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ELEMENTARY PRINCIPLES OF ATOMIC ENERGY

BY DR. R. E. LAPP

ARMED FORCES SPECIAL WEAPONS PROJECT

INDOCTRINATION COURSE FOR MEDICAL OFFICERS

OUTLINE

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ELEMENTARY PRINCIPLES OF ATOMIC ENERGY

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Part One - ATOMIC STRUCTURE AND RADIOACTIVITY

Section 1.00 Introduction

We realize that many of you have little background in the field of atomic energy and we would like to give you a few words of encouragement before launching into this week's discussion. It is our purpose to give you some concept of the physical basis for understanding radioactivity and fission. This will be done in a non-mathematical and we hope, an understandable, manner. As the material is to be given later this week.

From this introductory lecture, we hope that you will gain an appreciation of the dimension of nuclear particles and of the magnitude of nuclear forces. By carefully reading through this material and by referring back to it, you will soon acquire a familiarity with the many strange terms which are to be used throughout this week's discussion.

Section 1.01 The Electron - Unit of Negative Charge of Electricity

Before proceeding to a discussion of the atom and its properties, we shall look briefly at the smallest particle of matter which bears a negative charge of electricity. You are all familiar with the word-electron-but perhaps its properties are not so well known to you. In vacuum tubes, such as those used in any radio, electrons are produced by a hot filament in the tube elements. These electrons are evaporated off the glowing filament by the high temperature which is created in the filament. Careful measurements have shown that all of these electrons have the same physical properties. Furthermore, electrons produced from a glowing filament are exactly the same as electrons produced by other means, as for example, by release from a photoelectric cell.

The electron is the lightest particle known to man and weighs only 9×10^{-28} grams. Now this terminology - a scientific shorthand - may not be familiar to you. It is simply a convenient exponential way of expressing the value of an extremely small quantity. For example, the quantity 0.01 can be expressed in this way as 10 raised to the minus 2 power (i.e. 10^{-2}). Here the negative exponent has the value of the number of zeroes in the denominator of the fraction 1/100. On this basis the quantity 9×10^{-28} grams is equal to the fraction - 9 divided by 10 raised to the 28th power. This is simply 9 divided by the quantity (1 followed by 28 zeroes). Written out longhand it is:

$$\frac{9}{10{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000}$$

It should be clear from the above example that it would be extremely

awkward to deal with such an unwieldly fraction and it is therefore convenient to use the shorthand form as 9×10^{-28}.

The vast majority of all electrons found in nature are not "free" in the sense that they are not attached to something else. We know that electrons are more or less tightly bound in a larger structure which is known as the atom.

Section 1. 2 The Atom - Its Size and Properties

Certainly, all of you are familiar with the concept of a chemical element. An atom is simply the smallest part of a chemical element which enters into a chemical reaction. In this lecture we shall be concerned with events which take place within the atom and it is therefore necessary to talk about the structure and constituents of the atom. For an understanding of atomic structure and for a visualization of a model of an atom, you may find ARMY TALK no. 157"A NEW WORLD WITHIN THE ATOM" very helpful.

The concept of the atom as a structure which is mostly "space" is one which can be appreciated best by realizing the magnitude of atomic and nuclear dimensions. 1 gram of hydrogen contains 6×10^{23} atoms: Thus even if this 1 gram of gas is contained in very large vessel, the number of atoms per cubic centimeter (1 inch equals 2.5 centimeters) is still extremely high. Each hydrogen atom has a diameter of about 10^{-8} cms (centimeters) which is less than one hundredth millionth of an inch. We now know that the simplest hydrogen atom is composed of two parts:

a) An inner part called the nucleus

b) An outer part called the electron shell

In later sections, we shall give more details about the nucleus and about the electrons which surround the nucleus. We conceive of the hydrogen atom as consisting of a central tiny core or nucleus about which circles a single electron. This core or nucleus of the simplest hydrogen atom is called the proton. A proton is simply a hydrogen nucleus and is formed by stripping off an electron from the hydrogen atom. It should be emphasized that the proton occupies negligible volume inside the hydrogen atom even though it constitutes almost the entire weight of the atom. Its weight is 1840 times greater than that of the electron.

Section 1.03 The Electrical Nature of Matter

Electrons are the only particles which are found within the atom outside of the nucleus and since these electrons are negligibly small in size as compared to the atom, it is clear that the greatest part of the atom is a void. Why then should the atom possess such apparent shape or rigidity which we know from experience it must have? The reason for this lies in the electrical nature of the nucleus of the nucleus as well as that of the electrons which speed about it in never ending orbital paths. In every normal atom, the nucleus carries a positive charge of electricity

which is exactly the same as the total negative charge of all the electrons within the atom. For convenience we call the charge carried by 1 electron as -e (it is actually 4.8×10^{-10} electrostatic units but you need not remember this number). It is known that each electron carries a discrete electric charge of -e units. We also know that each positively charged particle (proton) in the nucleus carries a charge of +e units. For any neutral (uncharged) atom the number of protons within the nucleus is exactly equal to the number of orbital electrons in the atom.

Between the protons inside the nucleus and the electrons outside of it, there exists an electrostatic force which pulls the particles together. However this force of attraction is just balanced by the centrifugal force due to the whirling motion of the electrons around the nucleus. Thus the electrons perpetually gyrate around the nucleus in orbital paths through the frictionless void of the atom.

Section 1.04 <u>The Outer Part of the Atom - Electron Shells</u>

Starting with the simplest atom (hydrogen has atomic number 1) the number of orbital electrons is one. The <u>atomic number</u> of any atom is equal to the number of protons in its nucleus. For heavier elements, more and more electrons are found in the orbits. Helium with Z=2 (Z is the atomic number) has two electrons; iron with Z=26 has 26 orbital electrons and uranium has 92 such electrons. These electrons arrange themselves in certain very definite ways about the nucleus and obey rigorous atomic rules. Thus they build themselves up about the atomic core in systematic shells which are peculiar in that each shell can contain just so many electrons. When one shell is filled, the electrons start another shell which is farther from the nucleus.

These electrons which are in the outermost shell are called the valence electrons. These determine the chemical properties of the atom. Since these outer electrons are farthest from the nucleus it is reasonable to suppose that these electrons will not be bound so tightly to the atom. The outer electrons are in a sense shielded from the nuclear charge by the inner electron shells so they cannot "see" the nucleus. On the other hand, those electrons in the innermost shell (the innermost shell is called the K shell) are close to the nucleus and are thus mostly tightly bound to it.

Section 1.05 <u>Ionization of an Atom - Ions</u>

If by some means we could pull one of the outermost electrons away from an atom, the resulting atom would no longer be electrically neutral but would have a net charge of +1. The process of removing an electron from an outer shell is called <u>ionization</u> and the resulting atom is called an <u>ion</u>. The combination of the positive ion and electron is known as an <u>ion pair</u>. An atom can be ionized by shooting high speed electrons at it. These minute projectiles may collide with some of the outer electrons and knock them out of their orbits away from the atom.

From a medical viewpoint the ionization process is of tremendous importance since it is the start of the process by which tissue suffers radiation damage.

By bombarding an atom with very high energy electrons it may happen that an electron in a K shell will be knocked out of the vacancy in it and one of the outer electrons jumps down into the K shell to fill it up. In jumping down (an electronic transition) energy is liberated from the atom in the form of an x-ray.

Section 1.06 <u>X-ray Emitted From Atoms</u>

The emission of an x-ray from an atom always occurs when an electron from an outer shell jumps down to fill a vacancy in a K shell. Because the electrons in different atoms (of different elements) are bound to their respective nuclei with different energy, the energy of the x-ray given off will depend upon the element which is producing them. You have undoubtedly used x-ray tubes which have had different elements for targets and know that the radiation from a tungsten target is much "harder" than that from a copper target. We have mentioned "hard" radiation but for any real discussion we must specify the radiation more exactly. To do this we can either refer to the energy of the x-ray or to its wave length. Energy is usually measured in terms of electron volts (at least for x-rays). An electron volt is that energy which is acquired by an electron in being accelerated across a potential of 1 volt. In x-ray tubes the electrons emitted by the filament are accelerated by perhaps 100 kilovolts (100,000) and we therefore say that these electrons acquire 100,000 ev (electron volts) of energy.

You are probably aware that x-rays sometimes behave as though they were "particles" and sometimes they act like "waves". In the literature x-rays are often called <u>photons</u> or <u>quanta</u>. It is a fundamental rule in physics that every particle has associated with it certain wave properties and can be described as having a definite wave length. Wave length in the x-ray region is usually measured in terms of 10^{-8} centimeters and since this is a very small quantity it is called by a special name of its own -- the <u>Angstrom unit</u>. It is abbreviated as A. If an x-ray photon has very high energy, say 1 million electron volts (1 Mev) it is said to have a short wave length or to be a very hard x-ray. On the other hand, if it is a photon of lower energy, say .03 Mev it is a long wave length x-ray and is said to be "soft".

Section 1.07 <u>The Inner Part of the Atom - The Nucleus</u>

The central core or nucleus of the atom while it is a dense sphere taking negligible space within the atom is composed of smaller units or particles. One of these particles -- the proton -- has already been mentioned but little has been said about it. In addition to protons, every atomic nucleus except ordinary hydrogen contains another type of particle -- the <u>neutron</u>. The neutron differs from the proton in that it does not have an electrical charge. It is electrically neutral. Both the neutrons and protons are about the same in weight and each is 1840 times heavier than an electron.

Therefore the bulk of all matter is found within the nucleus and perhaps an analogy will serve to illustrate this. If you as an individual were suddenly to be disintegrated so that the nuclei in the atoms of your body were free to come together all your weight could be concentrated in a speck on the end of a pin. Because the nucleus has its components so closely packed together we say that it has high density. Along with this close packing of neutrons and protons, there must be some force which acts between these particles. By the way, particles inside the nucleus are called nucleons. This force which acts between nucleons and holds the nucleus together is a queer type of force which is called "nuclear force". It is this force which is responsible for the enormous energy which is locked up within the nucleus. The energy is usually called the "binding energy" of the nucleus since it binds the nucleons together in a compact system.

Section 1.08 Gamma Rays Emitted from the Nucleus

When the nucleus of an atom suffers a collision with a high energy atomic particle, it may become "excited" by virtue of having absorbed energy from the collision. One way in which the nucleus can get rid of this energy is by emitting a photon. This photon is called a gamma ray and differs from an x-ray only in that it is generally a higher energy photon. Otherwise a gamma ray emitted by a nucleus is identical with an x-ray.

Once a nucleus emits a gamma ray, it may return to its former unexcited or normal state. Experimentally, many substances may be made to emit such gamma rays by irradiating them with a cyclotron beam or by placing them within a neutron reactor (a pile).

Section 1.09 Other Nuclear Radiations - Alpha and Beta Particles

About fifty years ago it was observed that certain elements give off penetrating radiations. Elements such as uranium and radium give off a variety of radiations and are called radioactive elements. The phenomenon is known as radioactivity.

Besides emitting gamma rays, these elements were observed to give off two types of particles.

A - Alpha Particles (α - particles)

These are just helium nuclei moving at high velocity. They thus are particles composed of 2 neutrons and 2 protons. Compared to an electron, such a particle is massive and might be expected to be easily absorbed in matter. This is actually the case for most alpha particles are completely stopped by a few sheets of thin paper. We shall see later that this very short range of action for an alpha particle does not prevent it from being effective in damaging cell tissue.

B - Beta Particles (β - particles)

Beta particles are simply ordinary electrons which are

emitted from nuclei. They move with high velocity (almost the speed of light) and are not as easily stopped in matter as are α particles. β particles of a few million volts energy will however be completely absorbed by several thin sheets of aluminum. You may be puzzled as to the origin of these electrons for we have already said that no electrons are inside the nucleus. You must think of the beta particle as being created in the process of emission just as x-rays are created. Before emission an atom does not contain an x-ray and in like manner neither does a nucleus contain any electrons.

Section 1.10 Radioactive Transformations and Isotopes

In the act of emitting an alpha particle, a radium (element 88) atom must undergo a change in its nuclear structure for the two neutrons and two protons which make up an alpha particle are subtracted from it. Technically, we say that the radium atom undergoes a radioactive transformation. To facilitate our discussion of these nuclear change-overs, we will introduce some nuclear nomenclature. For example, we shall describe the radium nucleus by the symbol $_{88}Ra^{226}$. Here the superscript is called the mass number and is numerically equal to the total number of neutrons and protons in the nucleus. The subscript 88 is the atomic number or charge and is numerically equal to the total number of protons in the nucleus. Thus we have a neat symbolic way of writing down basic information about an atom. Elements such as tin (atomic number 50) have a variety of different weights since some tin nuclei have more neutrons than others. These atoms of tin which have different numbers of neutrons are known as isotopes of tin. Thus isotopes are simply atoms whose nuclei have the same atomic numbers but different mass numbers. Some elements have only 1 isotope whereas others may have as many as 10 isotopes, each of which is present in different proportions.

When $_{88}Ra^{226}$ emits an alpha particle (symbolized by $_2He^4$ since an α particle has atomic number 2 and 4 nucleons in its nucleus) it transforms itself into a new element known as radon. This reaction may be written as

$$_{88}Ra^{226} \longrightarrow {}_{88}Rn^{222} + {}_2He^4$$

Radium goes to randon plus alpha particle

As you see, analogous to chemical reaction equations, we have "balanced" the equation and obtain a resultant atom of radon which has Z=86 and a total number of nucleons equal to 222. Instead of referring to this process as a radioactive transformation, we can also call it a radioactive decay or disintegration. Another point of terminology is to call the decaying isotope the "parent" and the disintegration product the "daughter". For radium, the parent is the $_{88}Ra^{226}$ isotope and the daughter is the heaviest product of the disintegration — the radon isotope $_{86}Rn^{222}$.

Section 1.11 Radioactive Series

Radium is only one of the many radioactive isotopes which occur in nature. It is perhaps the one with which you are most familiar. Radium is itself the daughter of a thorium isotope which in turn is a daughter of a

uranium isotope. There are thus a <u>chain</u> or a <u>series</u> of isotopes which are respectively parent and daughter to each other. The radon which is formed from radium is also radioactive and decays to form <u>polonium</u> and this forms an isotope of lead. Up to this point we can describe this series of events by the relation.

$$_{92}U^{234} \xrightarrow{\alpha} {}_{90}Th^{230} \xrightarrow{\alpha} {}_{88}Ra^{226} \xrightarrow{\alpha} {}_{86}Ra^{222} \xrightarrow{\alpha} {}_{84}Po^{218} \xrightarrow{\alpha} {}_{82}Pb^{214}$$

Uranium to Thorium to Radium to Radon to Polonium to Lead

The α over the arrow indicates that an alpha particle is emitted in the decay process. Now lead is commonly thought of as a very stable element. By that we mean that it does not undergo radioactive decay. However the isotope of lead which is formed in this radioactive series above is not stable. It has 214 nucleons in its nucleus and since it must have 82 protons, there are 214-82 or 132 neutrons in the nucleus of this atom of lead. Now in the lead atoms found in nature the heaviest isotope is $_{82}Pb^{208}$. Thus the isotope $_{82}Pb^{214}$ is much heavier than the heaviest natural lead isotope for it contains six additional neutrons. Instead of emitting an alpha particle which would make the <u>neutron surplus</u> even worse, the lead isotope $_{82}Pb^{214}$ emits a beta particle and the reaction is as follows:

$$_{82}Pb^{214} \longrightarrow {}_{83}Bi^{214} + {}_{-1}e^{0}$$

Lead goes to Bismuth plus Electron

In this case, lead changes to an element of atomic number higher than it since the emission of an electron is equivalent to <u>adding</u> a charge of + e to the Lead nucleus. In these nuclear reactions electric charge is always equal on each side of the equation i. e., charge is conserved. Since the electron has negligible mass the atomic weight of the isotope of bismuth is the same as the parent atom. By succeeding α and β emissions the bismuth atom is finally transformed to a stable isotope of lead = $_{82}Pb^{206}$. This isotope is then the end of this series which is called the uranium series. It must be remembered that in these decay processes penetrating gamma rays are also emitted but since γ rays have no charge and no rest mass, they do not affect the series relationships. In addition two other naturally radioactive series are known - the thorium and the actinium series. The latter both finally decay to stable isotopes of lead.

Section 1. 12 <u>The Rate of Radioactive Decay - The Curie</u>

You have probably been wondering about the time scale on which these radioactive transformations take place. Does the radium atom, for example, disintegrate in 1 second or in 1 year? Actually the process is statistical in nature and if we were able to look at one isolated radium atom, we might see it decay in a minute or we might have to wait a million years for it to disintegrate. If, however, we look at 1 gram of radium atoms, we see that there are so many atoms ($\frac{6 \times 10^{23}}{226} = 3 \times 10^{21}$ atoms) that there is an <u>average</u> value

for the <u>time during which 50% of these atoms will decay</u>. This time is called the <u>half life</u> and for radium it is 1590 years. If we start out with one gram of radium, then in 1590 years we will have only one-half gram on hand.

Radium is said to be <u>long-lived</u> but other atoms have extremely short half lives of the order of one millionth of a second. Still others like $_{92}U^{238}$ (the heavy isotope of uranium) is very long lived, having a half life of 4.5×10^9 years.

In order to calculate the activity of any sample of a radioactive material we multiply the number of atoms present as follows:

$$\text{Activity} = \frac{(\text{No. of Atoms})\ (.69)}{\text{Half Life (in seconds)}} = \text{number of particles emitted per second}$$

Suppose we calculate the activity of 1 gram of radium. Now 226 gms of radium are equal to 6×10^{23} atoms so 1 gram contains 2.6×10^{21} atoms and since the half life is 1590 years or 5×10^{10} seconds:

$$\text{The activity of 1 gm of Ra} = \frac{(2.6 \times 10^{21})}{5 \times 10}\ (.69) = 3.7 \times 10^{10}$$

disintegrations/second.

In practice this activity is called the <u>Curie</u> and is an accepted standard unit. You are perhaps familiar with the millicurie (mc) unit which is one thousand times smaller than the Curie. A millicurie of radium gives off 3.7×10^7 particles per second (37 million particles in one second).

Section 1.13 <u>The Quantity of Radiation - The Roentgen</u>

In treating a patient with radiation from a radium capsule it is necessary to measure the dose which is given. For this purpose we use a unit called the Roentgen named after the discoverer of x-rays. The Roentgen abbreviated is <u>r</u> is defined as that <u>quantity of x-radiation</u> which on passing through <u>1 cubic centimeter</u> of <u>normal</u> air produces <u>1 electrostatic unit</u> of <u>ions</u>. While it was originally defined only for x-rays, the definition is equally valid for gamma rays. A smaller unit, the milliroentgen (mr) is often used in practice. The definition is perhaps not too meaningful to you because of the term - electrostatic unit - which is used. Physically, one should think of the definition as meaning that the quantity of x-rays which is measured by a certain number of ions produced in a standard volume of air (roughly, 2 billion ion pairs per cubic centimeter of air).

Later on you will see that different types of instruments can be used to measure x-radiation. These are ionization chambers, Geiger-Muller counters, and photographic emulsions. One should sharply distinguish between two types of measurements -

A - Those that measure the <u>dose</u> or total <u>quantity</u> of radiation.

B - Those which give the <u>dose-rate</u> or the <u>intensity</u> of radiation.

Dose is measured in roentgens whereas dose-rate is measured in terms of roentgens/second or roentgens/minute or in other time units. It is one thing to give a patient a dose of 1r of x-rays and quite another to expose a patient to a dose-rate of 1 r/second. In the latter case, the patient receives a 1 roentgen dose in one second and a 60 roentgens dose in 1 minute. In one hour the patient would be dead or would be as good as dead.

Part Two - NUCLEAR FISSION AND THE CHAIN REACTION

Section 2.00 Introduction

Being thus prepared with a knowledge of radioactivity and nuclear radiations, we are in a position to discuss the phenomenon of nuclear fission. We already know that the nucleus is a compact aggregate of neutrons and protons which are bound together by nuclear forces which act between these particles. If by some process, this compact nucleus can be split, it is known that part of the mass of the original nucleus will be transformed into energy. To appreciate this, we must discuss the mass-energy relation which was first put forth by Einstein.

Section 2.01 The Mass-Energy Relation or $E=MC^2$

If in any reaction where there is a decrease in mass of the reaction, Einstein's mass-energy equivalence law requires that this mass must be converted into some form of energy. The resultant energy may be evident in any one of several ways. For example, radiation may be emitted as in gamma ray emission (radiant energy) or particles may be given high velocity (kinetic energy). In any event, the

$$\text{Energy Released} = (\text{Decreased in Mass}) \times (\text{Velocity of Light})^2$$

or $E = MC^2$

Suppose, for example, we split a Uranium 235 atom ($_{92}U^{235}$) into two parts and assume that 1/4 of a mass unit is converted into energy. One mass unit is about the weight of one proton and is equal to 930 million electron volts of energy. One quarter of a mass unit, then amounts to about 230 Mev. Since the original $_{92}U^{235}$ atom weighs 235 mass units, it is equivalent to a total energy of 220,000 Mev. Thus only

$$\frac{230}{220{,}000} \times \frac{\text{Mev}}{\text{Mev}} = \frac{1}{1{,}000}$$

of the total energy content of the uranium atom is released in this splitting (fission) process. In fission, the greatest part of the 200 Mev of energy is released in imparting high velocity to the split atom parts (fission products).

Section 2.02 A Physical Picture of the Nucleus

In the foregoing sections, we have indicated something of the nature of the nucleus. Let us now look a little closer at this tiny

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cluster of nucleons which forms the heart of the atom. We can form a very useful model or picture of the nucleus by thinking of it as analogous to a liquid sphere or water droplet. Inside the confines of this sphere, the neutrons and protons are in a constant state of violent motion, bumping into each other incessantly but always remaining inside the sphere. So strong are the forces between the nucleons that they do not let each other out of "view" and pull each other tightly together. As evidence of this close packing of neutrons and protons inside the nucleus is the fact that the uranium-238 atom (the heaviest naturally occurring isotope) is only slightly larger in diameter than the nucleus of a light element such as aluminum.

Outside the nucleus, the extremely strong nuclear forces are not felt because they have a very short range of action. However, the protons inside the nucleus make themselves known outside the confines of the nucleus by their electrostatic "field". This "field" forms a barrier around the nucleus which prevents any charged particles from entering the nucleus. If, however, the particle which seeks to enter it is uncharged, it cannot "see" the particle and offers no resistance to its entry. For this reason, neutrons of low energy can easily slip inside the nucleus whereas protons of even very high velocity are barred.

Section 2.03 A Model of the Fission Process

It is a property of a few very heavy nuclei such as U^{235} that when a neutron is added to them, they react very violently by splitting into two almost equal parts. The process is called nuclear fission or simply fission and the isotopes which exhibit this unusual behaviour are called fissionable. The heavy products of the fission reaction, i.e. the two halves of the heavy atom are known as fission products.

We can picture the fission process by bringing into consideration the liquid drop model of the nucleus which we have just discussed. Let us imagine that before the neutron enters the uranium 235 nucleus all the 92 protons and 143 neutrons are in constant motion inside the spherical nucleus. Let us assume that because there nucleons are so close together and move about so rapidly so that they lose their individual identity and may be thought of as forming a fluid or liquid drop of uniform density. With the intrusion of a neutron into this contented system, the liquid drop has energy added to it and become excited. The particles inside the nucleus are set into more violent motion and the drop begins to lose its spherical shape. As it deforms into a non-spherical shape it sets up rapid oscillations which deform it still further into a dumbbell pattern. At this point the original sphere is essentially drawn out into two smaller spheres with a tenuous connecting like which then snaps. Then the two fission products shoot away from each other with high velocity. All this happens in an exceedingly short time interval of less than 10^{-12} seconds and may be thought of as an instantaneous reaction.

Section 2.04 Neutrons Released in Fission

When fission occurs, it is known experimentally that neutrons are

released. These neutrons are mostly (over 99 percent) emitted within an extremely short time of less than 10^{-10} seconds but a small fraction of one percent are delayed for as much as one minute after fission has occurred. All neutrons whether prompt or delayed are emitted by the fission products. In addition to neutrons, gamma rays, beta particles and sometimes alpha particles are emitted in the fission process.

Let us write down a reaction equation for a fission process

$$_{92}U^{235} + {}_0n^1 \longrightarrow {}_{46}Pd^{117} + {}_{46}Pd^{117} + {}_0n^1 + {}_0n^1$$

Uranium 235 Neutron 2 Palladium Isotopes 2 Neutrons

This assumes that the nucleus splits into two equal parts. As we shall learn later this is an improbable occurrence in natural fission.

If one looks in a table of stable isotopes one finds that the heaviest natural isotope of palladium is $_{46}Pd^{110}$ while the palladium isotopes shown in the reaction equation are much heavier, having seven more neutrons per atom. From experience, we know that these abnormally heavy isotopes are not stable and must by some means make up for the abundance of neutrons in their nuclei. This can also be thought of as a deficit of protons in the nucleus. It is thus understandable that neutrons are so quickly emitted by the fission products.

Section 2.05 Radiations From Fission Products

It would be rare for a pair of fission products to have the same mass and we know that it is much more common for one of the products to be heavier than the other. In general, there are two groups of fission products, one with an average mass of about 95 and the other of about 139. Just why the two fragments are unequal in mass, we do not know.

We do know, however, that the fission products are intensely radioactive, emitting high energy beta particles and gamma rays. By emitting β-particles, the isotopes which contain too many neutrons (or too few protons) tend to make themselves more normal since we have explained that β-emission is equivalent to changing a nuclear neutron into a proton. Because the fission products are born with such extreme neutron excesses (or proton deficits) it requires four or five separate β-decays to result in stable atoms. Thus each fission product is often associated with a chain of radioactive isotopes and for this reason we speak of these as fission chains. Almost all fission products emit very penetrating gamma rays in addition to beta particles. The half lives for the various fission products vary from a fraction of a second to many years.

The result of fissioning a large number of atoms is that we have an aggregate of many different fission products representing almost every element from atomic number 40 to 70. This fact makes the chemical decontamination of fission products a very difficult task.

Section 2.06 The Chain Reaction

If we wish to talk about the fission of large numbers of uranium atoms, it is necessary to have large numbers of neutrons available. Because the fission process requires only one neutron to initiate it and yet gives off between one and three neutrons per fission, it is possible to use fission neutrons to start a "chain" of fission reactions. Each fission adds more neutrons to the reaction so that more and more reactions are possible. Such reactions are called self-sustaining or chain reactions.

Since the fission process occurs so quickly, it is conceivable that if we were to properly assemble a certain "critical" mass of fissionable material such as U-235, we could set off a series of fissions which would proceed so quickly that the recoiling fission products and radiations would raise the critical mass to a multi-million degree temperature within fraction of a second. By definition, such a process would be explosive in nature. It is important to emphasize that the recoiling fission fragments which move with high speed cause the material through which they move to become hotter by kinetic collisions with other atoms. It is this heat due to the motion of the fission fragments which causes an explosion to result. In like manner, if the energy is released at a slower rate, the heat may be tapped to be converted into power.

Prior to World War II, no pure U-235 was available. Ordinary uranium metal contains 140 times more U-238 than it does U-235. Now U-238 is not suitable for a chain reaction because when it absorbs a neutron into its nucleus, it merely changes into a heavier element without fissioning. Since the two isotopes of uranium are chemically identical, they had to be separated by exceedingly difficult physical methods. In fact, the methods presented so many technical obstacles, that the Manhattan Project set up huge plants which used nuclear reactors running on natural uranium to generate a new man-made fissionable material - plutonium.

Section 2.07 Plutonium - A Man Made Element

With neutrons released in the fission of the small amount of U-235 present in natural uranium metal, it was possible to sustain a chain reaction in a massive graphite uranium pile. Under proper conditions a large number of the fission neutrons released in the pile can be absorbed by the U-238 atoms. This results in an unstable U-239 nucleus which rapidly decays by beta emission as follows:

$$_{92}U^{238} + {_0n^1} \longrightarrow {_{92}U^{239}} + {_{-1}e^0}$$

Here Np is the symbol for the new transuranic element neptunium. Neptunium is itself radioactive and soon decays to form an isotope of element 94 which has been named plutonium. Thus $_{93}Np^{239} \xrightarrow{2.3d} {_{94}Pu^{239}} + {_{-1}e^0}$

The figure 2.3d over the arrow means that this reaction has a half life of 2.3 days.

Plutonium is a dense silvery metal similar to uranium U-235 in that it is fissionable with slow neutrons (i.e. neutrons which are of low energy). Like U-235 it is also an alpha emitter and since it has a half life of 24,000 years, it is much more active than U-235 which has a half life of 7×10^8 years. The alpha activity of plutonium is sufficiently intense so that it constitutes a dangerous health hazard of about the same type as radium when it is deposited in bone matter.

Section 2.08 <u>The Concept of Critical Size</u>

One of the unique characteristics of an atomic explosive is that it must be assembled into a certain <u>critical size</u> before it can explode. The reason for this unusual characteristic is that the chain reaction will not be a self perpetuating one unless there are sufficient neutrons to cause continued fission. Suppose, for example, we wish to run a chain reaction at a rate of 500 fissions per second. Suppose, further, that each fission generates exactly two neutrons. This requires that one out of every two neutrons generated must be used to create more fission, so that we have to have 500 neutrons being used every second to cause fission. This leaves an additional 500 neutrons which we can afford to "lose" from our system either by absorption (not leading to fission) or by loss through escape from the system. When the number of neutrons being produced over and above those needed to keep the fission reaction going at a fixed rate is exactly equal to the number of neutrons lost from the system, we say that the system is <u>critical</u> and this mass of material is called the <u>critical mass</u>. Masses less than this are called <u>sub-critical</u> and larger ones are known as <u>over-critical</u> masses.

The trick in detonating an atomic bomb is to make an assembly of fissionable material over-critical as fast as possible and keep it together long enough so that an appreciable fraction of the atoms are fissioned. If one simply stacked up blocks of sub-critical blocks of U-235 until the assembly was over-critical, the chances are that no explosion would result. There would be a neutron "flash" and the heat generated by the fission of some (a small fraction) of the atoms would push the blocks apart and make the assembly non-critical. However, the neutron flash would be dangerous.

Section 2.09 <u>The Atomic Bomb - A Possible Mechanism</u>

A logical way to assemble an atomic bomb might be to take two hemispheres of fissionable material each of which is sub-critical and bring them very quickly together to form an over-critical mass. A gadget which might accomplish this result is shown in the projected diagram. One hemisphere of pure U-235 might be imbedded in a large mass of material (tamper) placed at the target end of a gun barrel. At the other end of the barrel might be another hemisphere which serves as a projectile. Separated by the length of the gun barrel, each hemisphere would be sub-critical and safe, but by firing the one hemisphere down the barrel, it would attain a high velocity and weld itself together with the target into an over-critical mass. The

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inertia of the projectile together with the force of the expanding gas behind it might hold the system together for an appreciable length of time so that a large amount of the uranium is fissioned. This might insure a high "efficiency" for the reaction.

While it is not possible to calculate the exact magnitude of the activity associated with the radiations emitted by an atomic explosion without revealing classified information, it is possible to make crude calculations based upon very simple assumptions. These show that there is a truly fantastic quantity of radioactivity which results from an atomic detonation equivalent to more than 1 million tons of radium. Later on in the week, the results of Test Baker will be discussed and this point will be amplified as well as clarified. The half lives of the fission products are, in general, all shorter than that of radium; therefore the activity of the Bikini lagoon area is now very much less than if 1 million tons of radium had been dumped into it.

Section 2.10 Radioactivity Induced By Neutrons

As Army officers, you will be most interested in and concerned with the new type of damage which is inflicted on personnel by atomic explosions. From your experience in the last war, you are familiar with blast or concussion effects and with flash burn injuries. However, "radiation damage" presents new and challenging problems.

While we have discussed various phases of radioactivity, we have not mentioned radioactivity which is induced in materials by the capture of neutrons. We shall briefly discuss the artificial activity induced by neutrons.

If a neutron strikes a nucleus of some element such as sodium it may be absorbed or captured by it. This process is described by the reaction equation: ${}_{11}Na^{23} + {}_{0}n^{1} \longrightarrow {}_{11}Na^{24}$

The resulting sodium atom is not normal and emits radiation. For this reason it is called radio-sodium. Radiosodium emits a beta particle of 1.4 Mev and also a gamma ray. Thus, if an atomic bomb explodes close to sea water there will be a neutron induced activity produced since salt in the sea water is present to about 35 grams per liter. Radiosodium has a half life of 14.8 hours and for this reason the activity will persist for a few days before becoming negligible in intensity. Other elements can also be activated by neutron iradiation. This is the means by which carbon 14, radioiodine and radiophosphorus are made. You have heard of these radio-elements in the public press.

Section 2.11 Conclusion

We caution you that the basic principles of atomic energy are not to be learned in 1 hour or in 1 week. Depending on your background and

aptitude for the subject matter, you will sooner or later begin to feel "at home" in this new field but this process will require a considerable effort on your part. All that we can hope to do in this short space of time is to orient you in this relatively new work so that you will be better prepared to deal with it as it bears upon the military situation.

APPENDIX I

A SELECTED READING LIST OF ARTICLES ON ATOMIC ENERGY

1. "Radioactivity and Nuclear Physics" (D. Van Nostrand - 1947) J. M. Cork.

2. "The Medical Uses of Atomic Energy" Atlantic Monthly, R. D. Evans (1946).

3. "Explaining the Atom" (Viking - 1947) S. Hecht.

4. "Atomic Bomb Explosions" (War Department General Staff - R. & D. Division - 1947 Publication) R. E. Lapp.

5. "Nuclear Power - Its Military Application" (Coast Artillery Journal, July 1947) R. E. Lapp.

6. "Action of Radiation Living Cells" (Cambridge - 1947) D. E. Lea.

7. "Fifty Years of Atomic Research" (Article, Chemical & Engineering News - Volume 25 - Page 2495 - September 1st, 1947) S. C. Lind.

8. "Chemical and Engineering News" (May 25, 1946) A Series of Articles by such authorities as J. P. Oppenheimer, et al.

9. "Applied Nuclear Physics" (Wiley - 1946) Pollard and Davidson.

10. "Artificial Radioactive Tracers" Science 105, 349 (1947) G. T. Seaborg.

11. "The Particles of Modern Physics" (Blakeston 1943) J. D. Stranathan.

12. "General Rules and Procedures Concerning Activity Hazards" Declassified A.E.C. Report MDDC-247.

13. "Seminar Notes in Nuclear Science & Engineering" Mass. Institute of Technology, Department of Physics.

14. "The Atomic Bomb" Atomic Scientists of Chicago 1946.

15. "The International Control of Atomic Energy" U. S. State Department U. S. Representative Report #5 (1946)

ARMED FORCES SPECIAL WEAPONS PROJECT

INDOCTRINATION COURSE FOR MEDICAL OFFICERS

NUCLEAR RADIATION EFFECTS OF ATOMIC BOMB DETONATIONS

Dr. Herbert Scoville Jr.

The one factor which makes an atomic bomb detonation different from the detonation of any other type of weapon is the nuclear radiation produced. All high explosive weapons produce high temperature and high blast pressures, and the only difference in these respects between atomic weapons and conventional ones is the increased magnitude of the blast and thermal effect produced by the atomic bomb. However, no other weapon which has been devised to date is capable of releasing nuclear radiation.

SECTION I

Types of Nuclear Radiation

Nuclear radiations produced from the detonation of an atomic bomb consist of a number of different types. First, and most important, are the gamma rays. Gamma radiation is high energy, electromagnetic radiation similar to visible light or x-rays. In fact, gamma rays have quite similar properties to x-rays, the only difference being that they have more energy and are consequently more penetrating.

When an atomic bomb is detonated, gamma rays are generated chiefly in two ways. First, prompt gamma rays are produced directly as a product of the fission reaction itself. Since the fission reaction is completed within a minute fraction of a second after the bomb is detonated, these prompt gamma rays are emitted practically instantaneously at the time of detonation. The second main source of gamma rays are the fission products themselves. In an atomic bomb explosion the fissionable material, uranium-235 or plutonium, splits into two atoms of intermediate atomic weight. Since the fission reaction does not always take place in exactly the same manner, a large number of different elements are produced in any atomic bomb detonation. These fission products are almost all unstable and undergo radioactive decay emitting either or both gamma rays and beta particles.

The rate of decay of each of the various fission products is different, and therefore the half-lives of the individual fission products will vary from fractions of a second to thousands of years. (The half-life of a radioactive material is the time required for half of the atoms of that material to undergo decay). Because of this variation in the half-life, gamma rays from fission products are emitted in decreasing quantities from the time of detonation to years later. As an approximation, it may be stated that the rate of decay is inversely proportional to the time after detonation. In practice this means that one hour after the detonation the radiation from fission products is 1/60 of that at one minute. Similarly, one day later the radiation is 1/24 of that at one hour, and one year later it is 1/365 that at one day.

In addition to the gamma radiation produced by an atomic bomb detonation, there are large quantities of neutrons emitted. A neutron, one of the elementary building blocks of all matter, is a neutral particle with an atomic mass of one. Because of their lack of charge, neutrons are extremely penetrating. Neutrons which have a very high energy, (i.e. fast neutrons) are produced as a direct product of the fission reaction. In addition, a smaller number of so-called delayed neutrons are emitted within a few seconds of the detonation as a product of the decay of a certain few fission products. The delayed neutrons also have high energies. Fast neutrons are slowed down by collision with molecules in the air so that at any appreciable distance from the detonation, both slow and fast neutrons are present. When neutrons are absorbed or "captured" by an atom of matter, they frequently make that matter artificially radioactive. This "induced" radioactivity is then often an additional source of gamma radiation.

As previously mentioned, the decaying fission products emit beta particles as well as gamma rays. These beta particles are high speed electrons which are produced in a muclear reaction. Although the energy of these beta particles is high, their penetrating power is relatively low and would not produce appreciable effects more than a few meters from their source. They might, however, produce serious effects to personnel operating in an area contaminated with radioactive fission products. Beta emitting materials provide a serious hazard if absorbed internally.

Finally, a further type of nuclear radiation which may be present following an atomic bomb detonation is alpha particles. Any unfissioned plutonium or uranium-235 which may be present following a detonation will decay very slowly with the emission of alpha particles. Since alpha particles have little penetrating power and can be stopped by a sheet of paper, they do not provide any external radiation hazard, but if an emitter gains entrance into the body either by inhalation, ingestion or through a wound, then the alpha activity might provide a serious hazard.

SECTION II

Detonation of an Atomic Bomb in the Air

To date four bombs have been air-burst at varying altitudes. The Japanese results give a graphic indication of the effectiveness of such a detonation in producing casualties. From the observations at Hiroshima and Nagasaki, it may be said that a median lethal dose (i.e. a dose required to produce deaths in fifty percent of the personnel exposed) is obtained in the open at a distance of about three-fourths of a mile from the point of detonation. Thus most exposed personnel in an area of about two square miles would be killed by gamma radiation. A large number of people within this area would undoubtedly also be killed by burns or blast. Beyond the three-fourth mile radius the dose would decrease but, nevertheless, people at a distance of one and one half miles or more might suffer some effects from the gamma radiation.

Since the largest part of these gamma rays are emitted almost instantaneously at the time of burst, evasive action at the time the bomb was detonated would have little beneficial effect. Moreover, the great penetrating power of the gamma rays makes it very difficult to provide adequate shielding against them. However, personnel already within dugouts, heavily constructed buildings or large warships when the bomb is detonated might receive a certain amount of protection so that the effective radius of the gamma radiation would be reduced. As a rough approximation, it may be said that the exposure could be reduced by a factor of two by imposing one inch of steel between the individual and the point of detonation. Concrete is about one-third as effective as steel in absorbing the gamma rays. Dirt is about one-fifth as effective as steel.

Although large quantities of neutrons are emitted at the time of the detonation of an atomic bomb, their range of effectiveness is in most cases negligible by comparison to that of the gamma rays. Nevertheless, because of the even greater penetrability of the fast neutrons, a situation could conceivably arise in which the gamma rays were absorbed and yet the neutrons penetrated and produced effects. However, in most practical situations the neutrons can be neglected. They might, however, induce radioactivity in certain elements near the point of detonation, and these might provide some residual contamination. This was the case at Bikini where the sodium in the sea water captured neutrons and became radioactive. While this interfered slightly with operations during the test at Bikini, it was probably not of sufficient magnitude to provide a serious problem in war-time operations.

The residual contamination both from deposited fission products and neutron induced radioactivity will depend on the altitude from which the bomb is detonated. Thus, at Alamagordo where the bomb was exploded close to the ground, the crater contained considerable amounts of residual radioactive material. Samples of material from this site are still quite radioactive. The size of this contaminated area, however, was quite limited. In Japan, where the bomb was detonated at much higher altitudes, there was little detectable radioactivity within a few days of the detonation.

Most of the fission products and unfissioned material in an airburst are carried up to 40,000 to 60,000 feet in the atomic bomb cloud. These are then dispersed downwind and rapidly diluted so as to provide little hazard. However, there is a certain hazard downwind from a fall-out of this radioactive material, either as rain or as dust. For example fifty miles away from the Trinity site in New Mexico radioactive materials fell on some cows and turned their hair white in spots. No other harmful effects were noted on these animals. Because of this danger it will always be desirable to track the cloud as it moves downwind, and survey areas which might possibly be contaminated by material falling out of it. However, in all probability, such fall-out would be only a secondary hazard under war-time conditions.

SECTION III

Detonation of an Atomic Bomb Underwater

In an underwater detonation the nuclear radiation effects are quite different from those resulting from an air burst and are of considerably greater magnitude. The prompt gamma rays and neutrons are practically all absorbed by the water which surrounds the bomb. However, the fission products and unfissioned material are trapped in the water and carried aloft in the column and cloud. When the column descends, a concentrated mist shoots out from the base and spreads the radioactive materials over the surrounding area. The rain from this mist or so-called base surge will then deposit these materials leaving serious contamination over a large area. The exact area covered by this mist and subsequently contaminated will depend on the wind velocity. As a rough approximation the lethal area may be considered to extend about one-half mile upwind and two or more miles downwind. Serious contamination would be obtained at a much greater distance. At Bikini nearly all the target ships, although otherwise undamaged, were heavily contaminated, and if the bomb were detonated off-shore of some large city, the situation might well be catastrophic. In such a case a city might have suffered little visible damage and yet be essentially a ghost city. Most of the inhabitants at the time of the explosion would have been killed, evacuation would have been required for all others, and re-entry of personnel would be restricted to limited periods. The effect of such an attack on a number of our large cities might completely paralyze the industrial power of our nation.

To give an idea of the magnitude of the problem it might be best to compare the radioactivity of the fission products with that of radium. A gram of radium is an extremely large quantity of this material and in fact only a few pounds had been isolated up to the beginning of the war. In general one deals with thousandths or even millionths of a gram. The radioactivity from the fission products deposited in Bikini lagoon has, however, been estimated to be equivalent to thousands of tons of radium shortly after the detonation. This is a billion times the radioactivity from a gram of radium. Such is the truly fantastic radioactivity associated with an atomic bomb detonation.

Fission products deposited on the water would probably in most cases be diluted fairly rapidly, but would require tracking for appreciable periods of time. In the Bikini lagoon, which is a large body of water, intensities above tolerance were measured for almost a week, and even nontarget vessels operating in waters at sub-tolerance levels concentrated the radioactive material in their salt water lines and on their hulls in sufficient quantities to produce intensities above tolerances inside the vessels. This feature proved a great nuisance following the Baker test at Bikini, but would not have been sufficient to provide a serious hazard in war time. However, had the concentrations in water been higher, then a serious hazard might have been produced. For example, at Pearl Harbor the volume of water is small and there is little exchange of water with the outside ocean. Under these conditions the water contamination might provide a serious problem.

Material deposited on solid surfaces such as the decks of the target ships or the streets of a city, downwind of such a detonation would be far more serious since it would not be subject to any diluting influences. The radioactive materials would be strongly absorbed and their removal would provide an extremely difficult problem. Decontamination of radioactive materials is quite different than for chemicals, for the former must be physically removed while the latter need only undergo some chemical reaction. As previously mentioned, the decay rate of a fission product mixture can be approximated by a 1/T law. Thus, the radiation from the contamination would at one month be about 1/30 that at the end of one day. However, another 30 months would be required before the radiation would be reduced by another factor of 30. Thus, it is obvious that any area which is still dangerous one month after the detonation will remain so for long periods of time. At Bikini half the target ships still had topside radiation intensities greater than 1 roentgen per 24 hours two weeks after the test. This is ten times the tolerance intensity for continuous exposure.

As time goes on, the danger from the external radiation, (i.e. exposure to gamma rays from a contaminated surface) will gradually become a secondary factor, and the internal radiation hazard will become of primary importance. Thus, long-life fission products and unfissioned material may be absorbed into the human system by inhalation of dust or by eating contaminated food stuffs. Under these conditions, beta and alpha emitters provide a serious radiation hazard. This type of hazard may well make large areas permanently uninhabitable, but it would not preclude the use of the area for temporary operations provided adequate precautionary measures were employed.

One further point requires mention with respect to the hazards from an underwater detonation. Unlike the air burst, the radiation exposure obtained following an underwater explosion is accumulated over a measured period of time after detonation. Thus personnel in the open at a distance of one mile might have 30 seconds in which to take cover from the advancing radioactive mist. Direct exposure within this base surge would undoubtedly result in eventual death. Moreover unlike the air burst, the underwater detonation presents a hazard to any person entering the area sometime after the explosion has occurred. The extent of this hazard will, of course, depend on the time elapsed before such re-entry is made. Thus if re-entry into an area with an intensity of 3600 roentgens per 24 hours were made one hour after the detonation, then a lethal exposure of 400 r would be obtained in six hours and the very dangerous exposure of 100 r in 20 minutes.

SECTION IV

Summary

Air burst atomic bombs will produce lethal effects over an area of two square miles and measurable effect over an area of seven square miles as a result of the prompt gamma radiation emitted at the time of detonation. The residual radioactivity is of little importance except in the area close to the center of a low altitude explosion.

In an underwater detonation, radioactive fission products and unfissioned material will be spread by the cloud and base surge over a large area. The gamma radiation from these materials will be lethal to exposed personnel more than two miles downwind, and serious contamination will result at even much greater distances. This contamination will provide a serious hazard for an indefinite period of time. Prompt evasive action at the time of the detonation will permit the reduction of casualties and orderly evacuation and re-entry procedures will undoubtedly pay great dividends in minimizing the effects.

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BIOLOGICAL EFFECTS OF RADIATION

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HISTORY

The discovery of x-ray by Roentgen in 1895 opened the field of ionizing radiation to the world. In 1896 natural radioactivity was discovered by Becquerel during a study of fluerescent effects of different substances. While working with uranium, he found that photographic paper was darkened and what is euqally important, that the air adjacent to the salts would conduct electricity and discharge an electroscope. In 1898 the Curies isolated radium from pitch blend ore. Ir was aoon after the discovery of x-ray that the biological effects of radiation on skin were noted. This was the first indication of a biological hazard. Becquerel's classical accident is worth recording. He carried a vial of radium in his vest pocket and developed a burn on the underlying skin.

During the next decade, radiation was used extensively as a therapeutic measure on almost every known disease and frequently with disastrous results. It was not until 1903-1905 that the marked sensitivity of the blood-forming organs and reproductive organs of animals sounded the first warning that other than skin effects were occurring. Since that time the use of x-ray and radium has been approached with more caution as the dangers were recognized.

This has been pointed out to show that radiation is not a new problem introduced by atomic energy. However, the increased seriousness of the radiation problem has stimulated more intense interest in studying the effects of radiation and especially the mechanism by which radiation produces biological effects. Previous to the Manhattan Project, the amount of radium available in the world could be measured in pounds while at present the amount of radioactive material available on the detonation of the bomb can be expressed in hundreds of tons of radium equivalent.

MECHANISM OF IONIZATION

The radiations with which we are concerned in atomic energy are gamma rays, and alpha, beta and neutron particles. The effect they produce on living cells is known as "ionization". Essentially it consists of a radiation or particle hitting an atom within the cell and striking off a negative charged particle or electron from the orbits and resulting in a positive charged atom and the negative electron which are known as an ion pair. The method of striking off the electron varies somewhat with the different radiations, but the end result is the same. It is the formation of the ion pairs that produces the major biological change in the cell.

When speaking of radiation effects, the quantitative unit of radiation must be understood. It is called a roentgen and it is defined as the quantity of x-ray which on passing through one cc of air, under normal conditions of temperature and pressure, produces one electrostatic unit of ions or more simply, the quantity of

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x-ray which is measured by a certain number of ions (about $1.6x10^{12}$ ion pairs) produced in a standard volume of air. The roentgen is valid for gamma rays and equivalent units applying to nuclear particles have been developed.

GENERALITIES CONCERNING BIOLOGICAL EFFECTS

1. Practically all radiation effects are either definitely injurious or of no value to the individual species from the standpoint of survival or competition. Ionization in a cell produces damage that varies in severity with many different factors. There is, however, no "stimulating" effect on tissues. A mobilization of protective mechanisms may be seen but that is a response of the body to injury, not a direct result of radiation.

2. Some injurious effects are permanent and some temporary.

3. Injurious effects vary widely in their severity.

4. Ionizing radiation produces not one, but many different effects, even upon the same specie or organism.

5. Some effects of radiation may appear in the descendants of irradiated individuals.

6. Injurious effects may be beneficial as in the treatment of cancer. In radiation therapy a favorable balance is sought between the beneficial destruction of cancer and the injurious effects to the surrounding healthy tissue. An interesting paradoz is presented here - that although irradiation will destroy cancer, it will also, under some conditions, produce cancer, as in the skin from repeated absorption of radiation.

INTERNAL AND EXTERNAL RADIATION

There are two methods by which an individual absorbs radiation:

1. External. Here the source is outside the body and the radiation passes through the skin to produce effects in the deeper tissues. With an external source, radiation effects may be stopped by removing the source, moving away from the source or by interposing adequate shielding between the body and the source.

2. Internal. In this case the source of radiation (radioactive material) is taken into the body by ingestion, inhalation or through a break in the skin. The fission products or other radioactive elements are then deposited in the various organs of the body, one of the more important localities being a deposition in the bones in close proximity to the bone marrow. When radioactive material is fixed in the tissue, it is excreted very slowly and so remains a constant source of radiation bombardment within the individual. There is no method by which

radioactive material can be neutralized or destroyed and methods to speed the excretion of the fixed material are unsatisfactory. The only limiting factor, other than excretion, is the normal decay rate of the radioactive element.

TOLERANCE LEVELS (Maximum Permissable Dose)

A better term for the "tolerance dose" is the "maximum permissable dose" but common usage still carries on the older term.

Past experience in using x-ray and radium for diagnosis and therapy and laboratory experience in radiation has developed levels of radiation which at least tentatively are considered safe to absorb over a long period. This has been set for external radiation at .1 R/24 hrs. of gamma or an equivalent maount of the other radiations. In all industrial processes this figure is not exceeded except in emergency. During war time military operations it may be necessary to exceed .1 R/24 hrs. but an acceptable figure for the so-called "calculated risk" has not been developed. In peace time, however, the armed forces must follow the accepted standards of industry.

With regard to internal radiation, the goal is no absorption. Specifically, in plutonium work, one microgram fixed in the body is sufficient to compel complete withdrawal from radiation work for life. An historic example of internal radiation injury is the bone cancer and the deaths among the radium dial painters. The tolerance dose for radium fixed in the body is only .1 microgram.

Lethal Dose. The lethal dose is fairly well established and current thinking places the 50 mld (median lethal dose) or the dose which will be lethal for 50% of individuals at 450 R and 100% lethal at approximately 600 R. It must be remembered that when we speak of 450 R as being lethal, we are speaking of irradiation of the entire body or total body radiation. Doses up to thousands of roentgens may be given to a small confined area of the body without causing serious injury except to the desired area. An example is the irradiation of localized cancer.

BIOLOGICAL EFFECTS IN TISSUES

Many theories have been advanced as to the mechanism of injury from ionization, but the answer is still unknown. Among the more common are:

1. Some chemical change which interferes with the normal interchange between the nucleus and the rest of the cell;

2. Changes in permeability of the cell membrane;

3. Production of a toxic substance in the cell;

4. Changes in the intercellular environment.

The answer to the above problem is being intensively studied at the present time by many workers in the field of radiobiology.

A single cell consists of several microscopically distinguishable parts, which differ in chemical make-up. Since, under most conditions, all these parts are irradiated simultaneously at random, it is not surprising that many effects may sometimes be observed in the same cell. Some of these effects can be directly observed by various microscopic techniques; for instance, chromosome breaks, increased granularity of protoplasm, change in affinity for various stains, cytolysis, swelling of the nucleus, or of the entire cell, etc. Less direct physical methods reveal other effects, such as changes in the viscosity of the protoplasm, or in the permeability of the cell membrane. It seems probable that only a small fraction of the cellular effects produced have yet been observed.

The complexity encountered in the observation of cellular effects is increased many fold when we attempt to observe or analyze the effect on many-celled organisms. Here we irradiate many different types of cells and tissues, each of which may exhibit its own peculiar pattern of effects. This becomes further involved with the possibility of a radiation effect on one tissue producing an indirect effect on others.

A latent period is frequently mentioned which is really a misnomer. It is the period which elapses between the time the tissue is irradiated and the effects manifest themselves. Obviously, this period is not latent, but one during which numerous successive changes are occurring, which eventually lead to the change finally observed. Concerning the nature of these intermediate changes we are in practically complete ignorance.

The radiation sensitivity of the different body tissues varies and the following is a list in the order of sensitivity beginning with the most sensitive.

a. Lymphoid tissue, bone marrow, blood lymphocytes, lymph nodes, Peyers patches

b. Polymorphonuclear leukocytes

c. Epithelial cells

(1) Gonads and ovaries
(2) Salivary glands

d. Endothelial cells, blood vessels and peritoneum

e. Connective tissue cells

f. Muscle cells

g. Nerve cells

TISSUE RESPONSES TO RADIATION

1. Concerning the sensitivity of tissue in general, the more primitive tissues (the blood forming and reproductive) are more sensitive to radiation than highly specialized tissues (brain).

2. Cellular Environment. Whether the effect of ionization is a direct one, taking place within the cell, or an indirect one, resulting from alterations in the environment, is still a matter of conjecture - both mechanisms may be active. As an example - dimished effect of radiation on extremely radiosensitive tissue when subjected to decreased oxygen supply. Cold - freezing definitely decreases radiosensitivity.

3. The reversability or recovery of damaged tissue is meant the return of the tissue to normal functioning, and depends upon the dosage absorbed and the type of tissue. Beyond a certain quantative absorption of radiation, the cell will die regardless of type. The reversability of any specific effect is dependent on reparative and regenerative properties of the tissue. Muscle, brain and portions of the kidney and eye cannot regenerate. Repair results only in scar formation with loss of tissue function. Other tissue, as blood forming elements, membranes lining body cavities or glands, depending on the dose, may regenerate and resume their normal functions, but tissues which have been damaged and regenerated may not respond after repeated ionization which makes it essential that a repetition of injury is avoided.

4. One of the problems of radiation is the variation in response of the different species and between identical cells or tissues of the same species to the same dosage of radiation. Because of this characteristic, it is impossible to measure effects in terms of severity to a single specimen and statistical methods of measuring must be applied.

The most convenient way of measuring most effects is to set up as criterion of effects some occurrence which may be classified simply as present or absent, such as inhibition of cell division, failure to grow, or death. Graded doses are given to various groups of biological objects and after the exposed cells or organisms have been scarred or injured or uninjured, the percentage of uninjured ones is plotted against the dosage. This yields a survival curve. The term "survival"here denoting the ability to perform a certain normal act in spite of irradiation.

An example of species variation can be seen in the following table.

The approximate doses of 200 kv-x-rays required to kill 50% of the animals are as follows:

Mice	500 r
Guinea Pigs	250 r
Rabbits	825 r

This species difference is very troublesome in a practical way. We very much need quantitative information concerning radiation effects on humans. It would be very fortunate if we could carry out experiments on laboratory animals and draw therefrom quantitative conclusions concerning man. Species variations reduce such conclusions at best to a semi-quantitative status.

5. The rate of radiation is another factor which must be considered. This response falls generally into two categories:

(a) A few biological effects resulting from a given dose are the same regardless of the rate at which it is delivered. These are the cumulative effects, and some genetic injuries fall into this category.

(b) For the majority of the biological effects, however, the effectiveness of a given dose increases if the rate of delivery is increased. Conversely, if the delivery rate of a given dose is decreased, the tissue response or injury is decreased. This is explained on the assumption of an increase in the radioresistance of a tissue under prolonged radiation or probably more logically it is based on a recovery factor of the tissue.

6. The degree of penetration of radiation will vary the biological response of the body as a whole, this response varying with the tissues injured. Alpha particles (relatively large mass and a heavily charged particle) are highly ionizing, approximately 10,000 times as effective as gamma rays. But the range of action is limited by their poor penetration (approximately 1/10 mm in tissue). This practically eliminates alpha particles as an external hazard as they may be shielded out with a few pieces of paper or the skin, but when they are deposited internally in a vulnerable organ as the bones, severe damage due to their high ionizing ability results. Beta particles (negative charge and negligable mass) which are about 100 times as effective in ionizing as gamma rays, have a similarly poor penetration quality (approximately 5 to 10 mm tissue). They are, however, an external hazard by virtue of their caustic effect on skin and if absorbed into the body are an internal hazard. Gamma rays, (uncharged electromagnetic radiation) have a much less degree of ionization than alpha or beta particles, but their ability to penetrate and reach the deep tissues makes them a particular hazard in external radiation. The penetration ability of neutrons (1 mass unit and no electrical charge) varies with their energy but in general is somewhat less than gamma and their power of ionization is about 5 to 8 times as effective as gamma rays which places this particle among the serious external hazards.

The following table is a comparison of the relative quantities of various qualities of electromagnetic radiation required to produce erythema of the skin: (This shows that the higher energy rays produce their ionization in the deeper tissues with a minimum amount of absorption in the skin and in order to produce a skin effect, must be given in higher doses.)

Radiation Range	Exposure to Produce Erythena
Grenz Rays	100 r
100 kv x-rays	350 r
200 kv x-rays	600 r
1000 kv x-rays	1000 r
Gamma rays	2000 r

ACUTE AND CHRONIC RADIATION

Acute radiation injury must be separated from chronic in any discussion of radiation injury. The acute results from dosage producing an appreciable effect that can be determined by clinical and laboratory examination. The subject will be covered separately by Colonel Cooney under Radiation Sickness. The chronic effects resulting from dosages ranging from the so-called tolerance levels to approximately 10-20 R/day are the subject of intensive research but little data on man is available. The results of animal experiments must suffice because of the unsuitability of exposing humans to this relatively unknown hazard. The most predominant effects expected of chronic radiation are shortening of the life span, premature aging, the production of malignancies, skin changes from beta and soft gamma rays and x-rays, and genetic injury. (The latter will be discussed separately.) In man it is said that radiologists and industrial workers with x-ray show increased incidence of leukemia. Recent work published however states that with mice, using doses ranging from tolerance to 8 R a day, the overall incidence of leukemia and lung tumor is not increased but radiation forces an earlier appearance of the disease. The higher the dose rate, the earlier the appearance. On the other hand, ovarian tumors are not a function of dose rate but are dependent upon a minimal dose starting the process, the future course of which is not influenced by radiation. This minimal dose is cumulative and unreversible and results in a higher incidence of tumors. Injury to mice testes, however, is found to be reversibile and responsive only slightly to accumulative dosage. Increased intensity of radiation or a short time dose period will increase the damage.

The above findings have not been given to confuse the picture but to illustrate the variation in responses of different tissue of the same specie and the difficulties facing a medical man in attempting to evaluate and tabulate the chronic effects of radiation on man.

BLOOD

The blood is frequently mentioned as an index of radiation exposure. As has been mentioned, the most sensitive tissues are the lymphoid tissues and the bone marrow. Observations of the blood count should reflect injury to the blood forming tissue. This is true for severe over-exposure; alterations in the blood picture may be observed within an hour after total body radiation. For exposure

There may be an initial leucocytosis which is not due to any stimulating radiation effect but to a mobilization of the leucocytosis from the bone marrow. This is followed by a leucopenia which may reach a severity depending upon the amount of radiation absorbed of practically zero white cells. During the recovery period there is usually a relative lymphocytosis. The red blood cells start to decrease in about one week and an anemia is a manifestation of severe bone marrow damage. For exposure to small quantities of radiation, the white blood count is not a reliable index. The daily normal variations, existence of low grade infections, and variations in counting technique are among the factors reducing its reliability in measuring the relatively small variations to be expected. A count on an individual exposed to frequent radiation showing a reduction even when compared to the individual's previously established normal, is not a positive indication of radiation injury. More importance can be attached to a slight reduction in count if the individual is a member of a group exposed to radiation and all show the same variation. That would possibly indicate an overtolerance exposure to radiation for the group.

REPRODUCTIVE ORGANS AND GENETICS

The elements of the reproductive organs which are injured by radiation are the progenetors of the adult germ cells and the genes which transmit the hereditary factors. Sterility can readily be produced by irradiation. The dose necessary for the male is about 800 R and in the female, 600 R for permanent sterility. Temporary sterility may be produced at much lower doses.

GENETIC INJURY

Genetics is a complicated and somewhat obscure science, scarcely considered by the average medical man. In radiation, however, it is constantly mentioned as a hazard in chronic radiation and no discussion is complete without the mention of possible genetic injury. It is especially important, as already mentioned, because the effects are produced by accumulative dosage without regard to dosage rate or wave length. In spite of its constant mention, little is known of the actual genetic effects to be expected. Its study in man is complicated by the long life span of humans, small number of offspring, lack of specific knowledge of dosage received, and difficulty of controlling experiments. Much of the information now available is the result of studying the fruit fly and various species of fish. The direct application of this information to humans is difficult.

In general terms, the gene is a germinal factor which carries hereditary characteristics. There are dominant and recessive genes. Recessive require like genes or like contributions from both parents for expression in the offspring while the dominant do not, but are expressed in the direct offspring. Mutations are changes from the normal within the genes. It is these mutations that produce abnormalities in the offspring whether they are deleterious or beneficial to the race. Mutations occur naturally and artifically. The artificial mutation produced by radiation are those with which we are primarily concerned. Mutations in dominant

genes may be detected in the next generation, while recessive mutations may go undetected for generations. The majority of the natural and radiation mutations are recessive, however, and little change can be expected in the first generation. Also being recessive, they will require like recessives for expression and the probability is small that they will meet in a future generation.

Mutations, whether spontaneous or radiation induced, are about 95% lethal or sub-lethal. This means that the offspring will die during gestation or shortly afterward. Of the viable mutations (about 5% of all mutations) about 95% are deleterious. Of these, about 96% pertain to other than sex chromosomes. The remaining are sex linked mutations which are the exception to the general rule of recessives requiring several generations for expression. They are expressed in the next generation.

In Japan the total dose received by the survivors is very low for clear cut genetic effects, but in the next twenty years through the sex linked lethals in females, a change in the male-female ratio may be seen. Ordinarily more males are born than females, but radiation may cause a decrease in male offsprings. The occurrence of defective offsprings may increase the stillborn birth rate and there may be an increase in infant morality which is again due partly to congenital abnormalities. All this is being studied in Japan on a long range program being planned by the National Research Council. Many years, however, will be necessary before significant results can be obtained.

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MEDICAL EFFECTS OF ATOMIC EXPLOSION

Colonel James P. Cooney

Medical effects from the atomic bomb may roughly be divided into three categories as follows:

1. Trauma
2. Burns
3. Radiation Injury

1. Trauma – Inflicted by the mechanical force of the explosion, either as blast or indirect trauma due to flying debris. As in the case of the bombing of Britain, the latter was much more important. The atomic bomb explosion differs from an ordinary bomb blast in the wide compass of its range. No one was closer to the bomb than several hundred meters. At that distance the peak pressure must already have fallen, and its duration must have greatly decreased in comparison with what it was in the center. The explosion did not have the trip hammer blow effect of high explosive, but was rather like a sudden violent gust of air which lasted for a brief but appreciable period.

Japanese medical observers on the spot could not find any cases of direct damage to the internal organs by the blast. Necropsy of the early cases shows no typical evidence of blast damage to the lungs. Many individuals reported having lost consciousness temporarily, with no history of direct trauma to the head. Observations of Zuckerman (British report) tend to discount cerebral concussion resulting directly from the blast. A report shows the total of 17 ruptured eardrums at Hiroshima and 22 at Nagasaki. According to the British investigators there is a great variation in the intensity of the blast pressure which will result in the rupture of the eardrums in man. In explosions where persons were subject to pressures estimated at between 45 and 100 pounds per square inch, less than one-half of a small group suffered rupture of the tympanum. The drum may, however, rupture under pressures as low as two to four pounds in excess of atmosphere. Facts of acceleration of pressure may also be important in determining the incidence of blast effect on the biological target.

a. Indirect effects of blast caused by falling walls, flying glass, etc. Windows were broken as far away as Kure, 20 km. The radius of complete collapse of the natives' wooden buildings was 2.4 km, almost symmetrically distributed about the center. The incidence of mechanical injury is about 60% between 500 and 1250 meters. It is only beyond 2700 meters that the incidence of mechanical injury begins to fall off rapidly. Even at 4500 meters, the incidence of mechanical injury in the survivor group is still 14%. Fatal injuries, however, are almost entirely in the zone of complete destruction.

Those indoors in heavy buildings, surprisingly, show a higher incidence of injury than those remaining in native Japanese buildings. Since most of the injuries were inflicted by flying glass and the concrete buildings having more glass

than those of the native type, the explanation of the paradox is clear. Furthermore, this ratio of injury applies only to non-fatal injuries in survivors. It is assumed that the total mortality from immediate trauma is higher in the Japanese buildings than in the concrete buildings at the same distance, the reason being that over a wide area of impact the Japanese buildings collapsed from blast while the concrete buildings generally retained their structural integrity. Exactly how much of the total mortality was caused by the traumatic factor will never be known, because within one-half hour following the blast both cities were swept by fire before rescue operations could be instituted. Consequently, even though mechanical injury was not directly responsible for death, it probably contributed vitally to the actual mortality. This accounts for the low incidence of severe forms of injury among the survivors.

The British estimate that a bomb similar to the one used at Nagasaki if exploded at the same height over a city such as London would cause complete collapse of normal buildings for a distance of 3,000 ft. from zero point, damage all houses beyond repair out to a distance of one mile, render houses uninhabitable without extensive repairs up to a distance of 1½ miles, and would render houses untenantable without immediate repairs out to a distance of 2½ miles. Over London the bomb would completely wreck 30,000 houses, badly damage 35,000 and damage from 50,000 to 100,000. Based upon a density of population of one person per 1,000 sq. ft., the bomb would kill 75,000 people. Compare this with a 500 lb. bomb dropped in the same area which would cause a mortality of six people and a block buster which would cause a mortality of 30 people.

b. Types and mechanisms of injury from one group of patients at a military hospital were as follows:

Fractures	11.5%
Contusions	53.8%
Lacerations	34.7%

Flying glass was the cause of the greater percentage of lacerated wounds. The fragments were so small that in many cases clothing was sufficient to protect the body. In one case, at 1,000 meters, the patient was struck by glass fragments which, even though they did not penetrate his trousers, it struck with sufficient force to pierce the skin of the upper portion of the bared torso and produce an injury.

2. Burns - The burns that occurred may be classified as "flash burns", which are the result of the direct action of radiant energy, and flame burns. The latter were relatively rare, for the reason that it took some time, perhaps one hour as stated above, for the fires that were started following the blast to spread within the city. Consequently, those who did not escape were burned to death.

The radiant energy covered the entire width of the spectrum, which resembled that of the sun. Let us now consider only the ultra-violet, visible light and infra red rays. None of these has a high degree of penetration, so that any solid

object, such as clothing or even leaves, was sufficient to produce a shadowing effect (outline of the man who was in the direct line of rays projected upon the asphalt of Bantai Bridge), only surfaces directly exposed to the rays were effected by them and thus results the so-called "profile" burns. The wood of dark colored telephone poles was superficially carbonized at 3,000 meters from the center. From the data of Ashe and Roberts, a temperature of 4,000 degrees Centigrade acting for approximately 0.5 seconds is necessary to produce a second degree burn. It appears that the injurious agents causing flash burns were of extreme intensity but lasted for a very short duration. Burns were remarkably common among those indoors, as it was summer and many of the windows were open. Burns were of no significance beyond 4,000 meters. Beyond 3,000 meters few burns required treatment and were merely emphasized by erythema. Fifty-three percent of the deaths attributed to burns died within the first week and 75% of the total within two weeks.

Symptoms associated with the burns varied from case to case but tended to follow a fairly definite pattern. In individuals close in, both burns and blisters were apparent in five minutes. Further out, in the vicinity of 1,500 meters, burns appeared in two hours' time and the blisters in from four to six hours. Within 2,000 meters, the burns appeared in about three hours and blisters after an elapse of 10 hours. However, in one patient at 2,000 meters there was vesiculation within 10 minutes.

a. Effects of radiant energy upon the eye - Direct injuries to the eye were remarkably few. Only a few palpebral burns were noted. The shadowing effects of the supra-orbital ridges and the blink reflex helps to explain this finding. Almost all of the patients had temporary amblyopia which lasted for an average of five minutes. A few patients had conjunctivitis and kerititis. Only one patient with a permanent scotoma from perforation of the macula was reported. Two patients developed traumatic cataract following contusions of the eyeball, A slight reduction in the transparency of the cornea was observed in some but they presented no subjective difficulties. One patient was so blinded by the flash that he was unable to distinguish light from dark for approximately two days but he made a complete recovery.

b. Keloid Changes - Keloid changes appeared frequently and in many cases are extreme. According to the Japanese physicians, the incidence of keloids is not a characteristic of race and they attributed its large incidence to the extreme temperature. However, it has been noted that where skin flaps were removed for plastic surgery, healing resulted in keloid changes. A follow-up of the "keloid problem" is being made by the Atomic Bomb Casualty Commission.

c. Pigmentation and depigmentation - Among the striking features of burns were the changes in pigmentation. At a distance of approximately 2,000 meters beyond center, the pigmentation was extreme and resembled a walnut stain. (Mask of Hiroshima) These burns were preceded by an intense erythema, which within a few days became increasingly pigmented. Surrounding the hyper-pigmented area is a sharp border in which is found a zone where there is even less pigment than normal skin. This zone represents an area where some melanophores have abandoned to enter the hyper-pigmented tissue. This pigmentation began to fade only in a few cases at four months and in many cases still persisted after one year.

Depigmentation of the exposed skin occurred in distances less than 2,000 meters. It was not necessarily associated with the scarring of the skin. There is histological evidence that loss of pigment in the basal layers can occur, even though the epithelium of the surface is not destroyed. At the margins of the depigmented zones there is found a narrow band of increased pigmentation externally to which there is again a vaguely defined depigmented border as described above. In the area of depigmentation the erector pilorum muscles were not damaged.

d. Etiology of the burns - Certain features of the burns suggest the action of specific wave lengths, probably in the ultra-violet range. The intensity of the pigmentation at 2,000 meters and the extreme depigmentation without destruction of the skin closer to the bomb is certainly an unusual result of thermal jury. It must be remembered that a relatively small quantity of air intervened between the patients and the bomb in comparison with the entire atmosphere and stratosphere which filters much of the ultra-violet from the sun. Gamma rays are not responsible for the sharply outlined pigmentary phenomena that has been described, since clothing would be no barrier to their action.

e. Protective effect of clothing - Clothing exerted a protective effect depending upon a series of inter-related factors that include:

(1) Distance from the bomb
(2) Color and shade
(3) Tightness of the clothing
(4) Thickness and number of layers

(1) Distance - A khaki uniform, coat and shirt worn together, were protective beyond 1,500 meters. Closer to the bomb, clothes were no protection. In some instances clothing actually caught fire and the resultant flame burns were among the most severe that were encountered.

(2) Color and shade - Darker shades absorb more heat than lighter shades. The effect of selected absorption in many cases was remarkable. At 1,600 meters in the case of a white rayon shirt with a pattern of dark blue polka dots, 2 mm in thickness and 1 cm apart, the polka dots were burned in the line of the rays but the intervening white material was undamaged. Extremely interesting is the effect upon cotton cloth with flower pattern in a light pink background. The flowers were dark red roses with leaves of varying shades of green. Some of the flowers were entirely burned out, others showing only scorching of the darker portions of the leaves and petals, while the intervening material showed no effects.

(3) Tightness - Where the clothing was more tightly stretched over the scapular and deltoid regions, burns were much more likely to occur.

(4) Thickness and number of layers - The protective effect of the seams and double layer effect of the folded over collar demonstrated the protective effect of the thickness of clothing.

3. Radiation Injury - The pathogenesis of the signs and symptoms will first be considered and then will follow an outline of the commonest clinical syndromes:

a. Skin: Epilation was frequently observed among persons who had been close to the bomb and who had survived for more than two weeks. At 500 meters the incidence was approximately 75% and fell off sharply at 1,250 meters. The time of the onset of epilation reached a very sharp peak between the 13th and 14th days after the bombing. Peak for males and females coincided. The hair suddenly began to fall out in bunches upon combing or general plucking, or it was found in considerable quantities on the pillow in the morning. This process continued for one or two weeks and then ceased. In most cases the distribution was that of an ordinary baldness, involving first the frontal and then the parietal and occipital regions, and sparing the temporal regions and the scruff of the neck. The eyebrows and even more so the eyelashes and beard were relatively resistant. In one group of patients coming to autopsy, 48 had epilation of the head, 8 of the axilla, 6 of the pubic regions, 4 of the eyebrows and 2 of the beard. Complete epilation is not necessarily correlated with a bad prognosis. On the other hand, 14% of all individuals who died of radiation effect at approximately the fourth week had no epilation. It can be assumed that such cases received some shielding effect such as concrete buildings, thereby filtering out the softer rays, with death resulting from the hard penetrating rays which have little effect upon the skin.

Even in severe cases, the hair had begun to return by the middle of October and two or three months later had fully returned. In no case reported was epilation permanent.

b. Oral and Gastro-intestinal Tissues: In many patients, severe nausea and vomiting occurred as early as 30 minutes following the detonation. In other cases, it did not occur until the next day. Thirty-two percent of the individuals within the first 1000 meters and 23% who were between 1100 and 1500 meters suffered from vomiting on the day of the bombing. The incidence fell sharply to 6% at 2000 meters. Diarrhea, sometimes sanguineous, occurred within the first few days in many patients. Membranes, similar to the type found in agranulocytosis angina, occurred throughout the gastro-intestinal tract.

c. Gonads: Histologically radiation effects on the testes were discernible as early as the fourth day and were profound in all fatal cases who had been within 1500 meters of the bomb. It was obviously of interest to study the sperm counts in the survivors. Only three of the 23 patients studied who had been within 1500 meters had a count in excess of 40,000 (lower limit of normal; of 39 who had been within 2 km, 13 had counts below 40,000) According to Macomber and Sanders, it is unusual for pregnancy to occur if the spermatozoa count is below 40,000. Several of the patients complained of a loss of libido or even loss of potency following the bombing. According to the Japanese physicians the return to normalcy has been slower in the male than in the female.

d. Ovaries: Histologically, the ovaries showed less striking changes than the testes. During the war years in Japan, there was a high incidence of amenorrhea,

increasing from 4.3% in 1932 to 12.0% in 1944. In 1944 the incidence among 316 nurses of the Tokyo Imperial University was 13.3%. According to the Japanese gynecologists, this was due to malnutrition, overwork, and anxiety associated with bombing. Thirty-six percent of the women in Hiroshima and 29% of the women in Nagasaki, between the ages of 15 and 49, who were within a distance of 5000 meters experienced menstrual disorders. The majority of these had one normal period following the bomb and had cessation for an average of three to four months. A year later no cases complaining of menstrual disorders attributable to the bombing were found.

e. Hemotopoietic System: In persons exposed to radiation, the lymphoid and hemotopoietic tissues underwent rapid necrobiosis. According to the Japanese the effect on the blood was biphasic. The lymphocytes dropped immediately and reached their low point in about five days. A few days later the granulocytes began to drop and about the same time the lymphocytes began to recover. About the same time the reds began to fall and about the end of the third week in many cases there was a recovery of the lymphocytes with a marked decrease in granulocytes and an associated anemia. However, in some cases as early as five days following the bombing white blood counts as low as 150 cells per cubic millimeter were reported. Specimen of vertebral marrow obtained after 10 days following the bombing showed an almost total loss of myelopoietic tissue.

f. Hemorrhagic aspects: Involved in this are four factors, namely, platelet factor, dietary factor, infection factor, and capillary fragility factor.

(1) Platelet factor - In 14 cases dying between the fourth to seventh week, in whom platelet counts were available, only two were above 60,000 per cubic millimeters. Most of the cases ranged between 10,000 and 25,000. In all of these cases the bleeding time was increased, in some as long as 46 minutes.

(2) Dietary factor - Needless to say vitamin C levels were low.

(3) Infection factor - Specific bacteriological data was unsatisfactory, however, there were cases of bacteremia demonstrated by streptecocci and bacilli found in freshly fixed tissues derived from the bone marrow.

(4) Capillary fragility factor - Capillary fragility was found in individuals at the fifth week and at that time seemed to run parallel to the white blood count.

g. Characteristics of the Hemorrhagic Phenomena: For convenience these will be referred to as purpura. In the skin, purpura was almost always manifested in patients dying from the third to sixth week, inclusive. Its incidence at various distances from the center ran almost exactly parallel to that of epilation and fell off sharply after 1250 meters. Purpuric spots tended to appear at about the same time as fever. Their peak is between the 16th and 22nd day, some five days later than the peak of epilation. Associated with their onset, there is an increased tendency to bleed from lacerations, fractures and burns. Healing of wounds was prolonged, coincident with the appearance of radiation sickness. The growth of granulation tissue stopped and no tendency to heal was shown. In those who survived, the

granulation tissue improved following recovery from radiation sickness associated with the purpuric spots on the skin. After the onset of the purpura of the skin, hemorrhages were also found in the gingivae and from the rectum, nose, urinary tract and respiratory passages in that order of frequency. The lungs are frequently involved in a necrotizing and hemorrhagic process.

CLINICAL SYNDROME

Patients who died of radiation sickness may be roughly divided into three groups as follows:

1. Patients who died within the first ten days - In this group there is histological evidence of radiation effects upon the skin, gastro-intestinal tract, lymphoid tissue, bone marrow, gonads or ovaries, but these have not been clinically manifested. There was no epilation nor purpura. Patients complained of nausea and vomiting on the first day of the bombing, followed by anerexia, malaise, severe diarrhea, thirst and fever. Death ensued in delirium. Profound leukopenia was present. Temperature records in all these patients were remarkably similar. Usually between the fifth and seventh days and sometimes as early as the third day, there was a step-like rise in temperature, usually continuing to the day of death. The earlier the fever, the more severe the symptoms and the poorer the prognosis.

A typical case: A 31-year old petty officer of the Japanese Navy was admitted to the hospital the night of August 9th. He was within 250 meters at the time of the bombing and suffered first degree burns to the back, neck and chest, contusions of the nose and right hand and an abrasion of the left elbow. On the 12th of August he began to complain of abdominal pain, nausea, anerexia, dizziness and diarrhea, which reached a frequency of 15 stools a day. At the same time his temperature began to rise and gradually continue upward until the day of his death, 15 August 1945. His blood count on 12 August 1945 was 4.6 million red blood cells and 150 white blood cells.

2. Patients dying the latter portion of the second week, third, fourth, fifth and sixth weeks or surviving severe symptoms. In this group, the anatomical and clinical results of radiation attained their acme. Epilation is prominent, as is the hypoplasia of the bone marrow. The hemorrhagic and necrotizing lesions are entirely comparable to those seen in aplastic anemia and agranulocytosis, and occur in the gums, respiratory and gastro-intestinal tract. Petechiae of the skin are almost always present. The sequence of symptoms is somewhat as follows:

In a typical severe case, the first evidence of the disease is nausea and vomiting on the day of the bombing, followed by a feeling of malaise. The patient then begins to improve and feels fairly well until about the beginning of the second week when epilation begins. A few days later he then again experiences malaise and a fever occurs, step-like in character. At approximately the same time pharyngeal pain may appear. Sanguineous diarrhea is a prominent symptom. The leucocytes and

platelets reach very low levels and there may be an anemic and generally debilitated condition for a long period.

A typical case: A twenty-five year old soldier was at the 104th Garrison, approximately 1000 meters, on the upper floor of a two-story Japanese building at the time of the explosion. Fragments of glass struck his right arm and shoulder, inflicting a laceration on the former and contusion on the latter. That night he slept in a field but he returned to the garrison on the 7th. Between the 10th and 14th, he worked on the east drill field and was able to march 15 km. Epilation began on the 20th of August but he continued to work. On the 27th he felt feverish and on the next day petechiae occurred. He was admitted to the hospital on the 30th of August. At that time he complained of malaise, headache and swelling of the gums. He had previously had malaise on the day after the bombing. The gingivae continued to swell and on 4 September they were extremely painful. He had a sore throat on 1 September and had dysphagia on the 7th. Superficial ulcerations of the angles of the mouth were noted and on the next day he had trismus. His temperature rose sharply on September 1 and attained 40.6 degrees centigrade. On the next day it began to fall and reached normal levels on the 14th of September. Petechiae began to clear on 9 September and he was sufficiently well on 4 October to be discharged. He was next seen on 23 October by members of the Joint Commission who found him at work on his farm. At that time he complained only of shortness of breath. His white blood count reached 1400 in contrast with a low of 900 on 4 September.

3. <u>Group 3</u> - In some individuals in whom the bone marrow fails to recover, the symptoms described in group 2 continue and the patients die after a chronic illness of extreme emaciation. In others, concomitant with partial or complete recovery of the marrow most of the striking manifestations classed as anemia disappear, but they nevertheless, succumb to the complications such as lung abscess, tuberculosis, etc.

A typical case: A 31-year old man admitted to the hospital on 5 September, 1945, complaining of epilation, gingival pain and high fever. At the time of the bombing he was in the military barracks approximately one km from the center. At the time he sustained a large wound of the occipital region and lacerations of the upper arm and dorsum of the left foot. On 25 August the scalp hair began to fall out and he began to complain of gingival pain. At the time of admission his temperature was 39.5 degrees Centigrade, pulse was 102. He was pale and undernourished and appeared moderately ill. There was a striking degree of gingival hemorrhage and ulcers were present on his lips. It was impossible for him to eat on account of pain. Epilation was complete but no petechiae were seen on the skin. On 15 September his fever increased and his coughing was so severe that he was unable to sleep. However, his external wounds began to heal. On 14 November there was hemoptysis of approximately 100 cc. On 15 November, he was in an agonal state and died. His total stay in the hospital was 72 days. On the 19th of September his red blood count was 2.2 millions, Hemoglobin 36, and white blood count 3200. On 8 November his red count had descended to 1.7 millions but his white blood count had increased to 4,300.

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FUNDAMENTALS OF RADIATION PATHOLOGY

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It is the intention to present in this relatively brief survey of the pathologic effects of radiation a continuation of the discussion begun under the subject of biological effects, and to present in addition, those changes seen in cellular systems or organs, and the body as a whole. Any division is a rather arbitrary one, although the aspect of total body radiation is relatively new and distinct. Total body radiation has assumed certain practical importance, and will be considered in some detail later.

The pathologic changes can be conveniently presented, after a few general considerations, by outlining the early and late changes in (a) tissue cells, (b) organ systems, (c) total body irradiation, and (d) internal radiation by radioactive materials introduced into the body either accidentally or therapeutically.

Sensitivity of the various body tissues has been well established in a general way, and has been expressed largely as the relation of one tissue to another. Figure 1 shows the relative sensitivities as indicated in two studies.

Reactivity of the tissues in terms of energy or actual ionizing effect from a quantitative standpoint is somewhat less definite. Variation in response to ionizing radiation has been indicated in numerous studies, but becomes of particular interest in total body radiation, since in this circumstance the variation is not only a question of death or survival over a relatively broad range of radiation dosage, but manifests itself as well by variations in organ responses, and presumably by an equally wide range in symptoms and clinical findings.

The effects of ionizing radiation are considered at the present time to be similar for all types of radiation - alpha, beta, gamma, x-ray, and neutron sources, when equal amounts from an energy and time relationship are absorbed in the tissues.

There is no satisfactory indication of any tissue effect of radiation other than destruction. Some recent evidence in animal studies would seem to raise this question. In prolonged exposures to tolerance and slightly higher levels, survival rates were higher in the exposed groups than in controls. This same tendency was noted in weight curves - the exposed animals showed weights consistently above those of the controls, due mostly to abdominal fat. This was considered not to be a castration effect. From a morphologic standpoint, however, the purely destructive effect has been emphasized in a recent report by Bloom.

In evaluating the tissue changes it is well to keep in mind that it is unlikely that all tissue has been subjected to the ionizing action of radiation. Microscopically any one or all of a number of cellular changes may be observed:

(a) Changes in staining characteristics, usually an increase in eosinophilic properties.

(b) Increased granularity, usually of cytoplasm.

(c) Vacuolation of variable degree.

(d) Swelling of cellular components.

(e) Distortion of cellular structures.

(f) Cytolysis, loss of definitive borders.

(g) Pyknosis.

(h) Changes in Golgi apparatus.

(i) Reduction in mitotic activity.

(j) Production of abnormal mitoses.

(k) Chromosomal changes (fragmentation, clumping).

(l) Increased refractile neutral red staining bodies within leukocytes by vital staining methods.

It should be emphasized, however, that these changes are found in conditions other than radiation, and are not specific, although highly suggestive.

Alterations in the noncellular tissue may include intercellular edema, swelling and hyalinization of colloid, swelling and fragmentation of elastic tissue.

A more direct approach to the cellular changes is found in observations on cellular viscosity, ciliary action, phagocytosis, cellular secretions and a few enzyme systems which can be demonstrated. Alterations in these processes have been described following radiation.

A general indication of the course of changes occurring after irradiation can be outlined briefly:

(a) Initially no changes may be found. Alterations in viscosity, and slightly increased acidophilic staining properties have been described as being among the earliest findings.

Cessation of mitoses and destruction of lymphocytes may occur in a short time - a matter of hours or less. Vascular dilatation and edema may follow, and in the case of larger doses, actual necrosis of tissue cells may occur, again depending on the relative sensitivity. These represent, of course, only the readily demonstrable changes, and are certainly an inadequate and relatively crude index of the tissue alterations.

(b) In small or moderate dosage recovery may occur with no residual lesion, may show the frequent pattern of repair by fibrous tissue replacement, or in other instances the pattern of repair characteristic of the organ. There is no indication

FIGURE 1

Desjardins*	Shields Warren**
Lymphocytes	Lymphocytes (and germ cells)
Granulocytes	Granulocytes
Epithelial cells	Epithelium
a) Basal of secretory glands	Smooth muscle
b) Basal of testis and ovarian follicles	Fibroblasts and derivatives
c) Basal of skin and GI tract	Neurons
d) Alveolar of lungs; bile ducts	
e) Tubules of kidneys	
Endothelial cells	
Connective tissue	
Muscle cells	
Bone cells	
Nerve cells	

* From Desjardins, A. U., Arch. Surg., 26: 926-942, 1932

** From Warren, S., Physiol. Rev., 24: 225-238, 1944

that the features of repair are specific or characteristic for any or all types of radiation. It is true that references to "radiation fibroblasts" and the picture of "radiation dermatitis" would lead one to assume these are unique to radiation injury, but such is not the case. On the other hand, these designations are useful ones in evaluating tissue damage and probable etiology.

The recovery stage in terms of tissue repair is often a matter of months or even years and, in the case of repeated or continuing exposure, becomes a much more important problem.

These late effects, in most instances involving the question of repeated exposure to radiation, are well established. It may be of interest to review these findings briefly.

(a) Atrophy and ulceration of skin, telangiectasia, fibrosis and vascular occlusion were early recognized as radiation effect.

(b) Carcinoma of the lung in the Schneeberg mines is considered related to the radioactive material present in the inspired air, and may have more modern counterparts.

(c) Bone sarcoma developing in the case of radium ingestion is well established.

(d) Carcinoma of the skin as a late effect of repeated exposure to x-ray irradiation is also recognized.

(e) Evidence of increased incidence of leukemia in those exposed to repeated radiation has been reported.

(f) Other effects have been discussed under the biological phenomena, such as genetic variation, shortening of the life span, etc.

Lymphoid tissue. - Changes in the lymph nodes have been described by many investigators. Relatively small doses produce in a short time nuclear degeneration of lymphocytes, and some distortion of the germinal centers. Congestion, swelling, and slight inflammatory cellular infiltration may occur. Mitoses are not seen for a period of time, until regeneration becomes active. Continued cellular degeneration is followed by increasing and active phagocytosis by large macrophages. Erythrophagocytosis occurs in addition to the phagocytosis of nuclear and cellular fragments. The inclusion of red blood cells in the macrophages is an early finding whose significance is not well understood. Repair in such instances of small dosage is rapid and apparently complete.

Somewhat greater dosage results in a picture of marked reduction in lymphocytes, leaving an almost empty reticular stroma with the persistance of a few small lymphocytes and a few larger reticulum type cells associated with the germinal

centers. Repair may take place, if the destruction has not been too great, apparently from the remnants of such centers, often with definite irregularity in the size, shape and pattern of the lymph node. If the damage has resulted in almost complete destruction, the area may consist of more or less condensed stroma and loose connective tissue containing a few scattered lymphocytes. Such areas are said to offer no resistance to lymphoid circulation.

The spleen is considered to be somewhat less sensitive than the lymph nodes, also with less complete regeneration. A similar cycle of changes occur. Loss of the lymphocytes may result in condensation of the stroma, and an accentuation of the reticular and sinusoidal pattern occurs. Regeneration, if it takes place, may show considerable irregularity in the cellular forms. Phagocytosis is active, and quantities of pigment may be present in the spleen after recovery. As in the lymph nodes, regeneration appears to proceed from the remaining reticuloendothelial elements. The heavy accumulations of pigment have been interpreted as evidence of excessive blood destruction, or failure of splenic tissue to dispose of the material, or both.

Thymus shows changes of a similar nature although phagocytosis and disposition of pigment are not seen as in lymph nodes and spleen.

Bone Marrow.- Marrow tissues are somewhat more resistant to radiation than lymphoid tissue. Destruction of cells appears to involve both the immature granulocytic and erythrogenic forms. Regenerative changes are seen early, within the first week. Pigment deposits, eosinophiles and plasma cells may appear. With particularly heavy irradiation, almost complete loss of cellular elements may occur, with only a few reticulum cells and perhaps an occasional focus of erythropoietic cells. The marrow in such cases possesses a peculiar gelatinous appearance grossly, with a deceptive red coloration arising from red blood cells within dilated vessels or dispersed extravascularly. Such marrow may regenerate adequately, or may result in an aplastic marrow with variable amounts of connective tissue. In the case of ingested radioactive material, any stage of hyperplasia or aplasia may be found, depending on intensity and distribution.

The correlation of this marrow picture with peripheral blood is not successful. The peripheral blood picture does not indicate in adequate fashion the processes occurring in the marrow. For example, the apparently paradoxical situation occurs in which a hyperplastic marrow is present with a relatively low count in the peripheral blood, a condition found in situations other than radiation effect. In these cases there is usually some lack of maturation within the marrow. This introduces the interesting circumstance which has been mentioned a number of times in the literature - what factors determine whether a given hematopoietic system, when subjected to repeated demands, stimulation, or insults, whichever term may be appropriate, will respond by hyper-* Warren cites a reference to the histories of two chemists working with radioactive substances over a period of years in the same laboratory. They observed no protective measures and died within 5 days of each

*plasia or aplasia.

other, one of aplastic anemia, the other of myelogenous leukemia. One can observe such cases clinically and from a laboratory standpoint, and encounter stages at which one is unable to indicate whether the case will progress to leukemia or to an aplastic picture. Again this is not a situation peculiar to cases of irradiation.

It might be well to bring to your attention several well known characteristics of radiation, shown particularly by the marrow. One is the destructive effect on tissues elsewhere in the body, when exposure is limited to a relatively small area. Another is the cumulative action of radiation. In successive exposures, the radiation necessary to show definite effects becomes less, and the periods necessary for recovery become longer. This has been expressed at times in the term "percentage recovery" for certain exposure.

Testes and Ovaries.- The reaction of the cellular elements of the seminiferous tubules to radiation differs. There is evidence to indicate that the primary spermatocytes are most sensitive, contrary to the general statement that more primitive cells are more sensitive. Next in order of disappearance are the spermatogonia, small spermatocytes, spermatids, and spermatozoa, with the Sertoli cells remaining, and proliferating to replace the germinal epithelium. In other instances the spermatogonia, the most immature germinal cells, have been observed to be the only ones persisting. The interstitial cells have been generally regarded as resistant to radiation.

Ovaries are somewhat less sensitive than testicular tissue. Maturing follicles have been described as the most sensitive portion, and corpora lutea as relatively resistant. In mice development of ovarian tumors following irradiation in the tolerance levels has been described.

Gastrointestinal tract.- Extensive studies have been carried out with regard to the gastrointestinal tract. Edema and degenerative changes in the epithelial cells occur early. Subsequent changes may include hyperemia, hemorrhage, cellular changes progressing to necrosis, often with a thick superficial fibrin membrane, and subsequent ulceration. Mitotic figures and atypical cellular forms are seen early, within a week, and are considered to be regenerative in nature, although at the same time closely resembling degenerated cells. These early epithelial changes in the gastrointestinal tract have been linked frequently with the profound toxic changes. Connective tissue areas of the walls of the gastrointestinal tract show edema, myxomatous and hyaline changes, the same areas often containing bizarre connective tissue cellular forms. Later effects include fibrosis, atrophic changes in the mucosa, such as reduction in number of glands, and in the gastric mucosa reduced number of chief cells. Ulceration is a relatively frequent occurrence, and often after an extended period of time.

Respiratory organs.- Pulmonary tissue is considered moderately sensitive to irradiation. A transient pneumonitis occurs, without apparent late effect. No significant changes have been described in the bronchial system.

Skin.- The pathologic changes in the skin have been described in great detail, and deserve special consideration because of the frequency with which they have been observed. The essential features include an early erythema occurring within a few hours to a few days, disappearing within a period of days, followed by a second occurrence of erythema 10 days to 4 weeks later. This second episode is considered to represent the culminating pathologic changes in the connective tissue and vascular bed of the corium, in contrast to the more direct injury to epithelial cells resulting in the early erythema. Pigmentation, epilation and ulceration may follow, with destruction of dermal glandular structures. The late picture of atrophy, hyperkeratosis, telangiectasis may develop after repeated small dosage without the preceding picture, with the possibility of malignancy. The accompanying histologic picture is characteristic. Epithelium is thin, with obliteration of rete pegs. Irregular acanthosis may be present with cellular abnormalities. The corium shows dilated vascular spaces, atrophic skin appendages, dense and hyalinized collagen, with variable basophilia, reduced or absent elastic tissue.

Without going into extended detail regarding other body tissues, it may be well to mention certain characteristic and relatively important reactions. The epiphyseal region of infants and children is particularly reactive to radiation. In the eye radio-conjunctivitis occurs with moderate dosage and may be followed by keratitis. Lenticular opacity occurs in the young eye tissues with moderate dosage, as compared to greatly increased dosage necessary in mature lenticular structure.

Other tissues which have not been discussed to this point generally are in the less reactive range, with few changes except in massive localized exposure. To this group belong nervous tissue, heart, liver, pancreas, bone, muscle.

Total body radiation, as has been mentioned, is a circumstance worthy of special consideration. Dosages used commonly, such as the erythema dose, approach or exceed the lethal dose when applied to the entire body. It is of considerable interest to define the changes at various levels of total body irradiation, and a certain clinical experience is available, as well as numbers of animal studies. Early and rather striking changes have been described in the gastrointestinal tract of animals dying of total body irradiation, with relatively slight changes elsewhere. Survival for a somewhat longer time places the organism in a period in which vascular damage and hemorrhagic phenomena are outstanding. The generalized destruction of hematopoietic tissue appears to be also a major factor at this and later stages. Findings at the later stages are those of severe infection without adequate cellular response, and presumably without adequate resistance.

The question of internal radiation by radioactive substances does not involve any differences from the tissue reactions described, other than the possible ones of localization and intensity. The action of radioactive substances internally depends on

(a) activity of the substance ingested, whether an alpha, beta or gamma emitter and the duration of its activity;

(b) behavior in the body - rate of excretion, affinities for certain tissue, and its course and localization.

For example, Sodium 24, which is highly diffusible in the body, gives the picture pathologically of total body irradiation from an external source.

The localization of many of the radioactive materials in relation to bone has intensified their effect. The well known lesions in radium poisoning may be used as an example — bone necrosis, particularly jaw, destruction of marrow with variable hyperplastic and aplastic changes, and the incidence of malignancy in the form of bone sarcoma. It is of interest that the amount of radioactive isotopes required to produce bone sarcomas, lymphomas and the like in animals is practically identical with that required to produce perceptible effects in the peripheral blood.

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PATHOLOGIC ANATOMY OF RADIATION EFFECTS

OF ATOMIC BOMB EXPLOSION

Colonel Elbert DeCoursey, M.C.

The material about to be presented represents the work of many investigators, American and Japanese. Tissues from radiated Japanese who died before late September 1945 were collected by the Japanese before we arrived. Besides the many who collected clinical material, Dr. Liebow of Yale was the Pathologist at Hiroshima and Captain Shields Warren and I, Navy and Army, worked together at Nagasaki. Most of the gross descriptions of early cases are Japanese, but we saw the preserved organs and obtained tissues for histologic studies. We performed autopsies after our arrival.

Before considering the radiation effects on the systems of the body, we might consider the relationship of lesions and time of death. In those patients dying during the first two weeks there is histologic evidence of radiation effects in the bone marrow, gonads, gastro-intestinal tract and skin not manifested clinically. In the group dying during the third to sixth weeks, bone marrow changes predominate, and neutropenic ulcerations and hemorrhagic symptoms are spectacular. General nutrition declines. Gross changes are at about the peak. Those dying in the third and fourth months show beginnings of recovery in bone marrow and hair regeneration but persistence of testicular and connective tissue changes. There is increased emaciation. The lack of nutrition is not based entirely on shortage of food. Intestinal lesions and other factors play a big part.

It must be emphasized that much of the Japanese material needs further investigation. The primary analysis has opened the way for future detailed studies.

SKIN: The quickly visible changes in Japanese affected by an atomic bomb were the pigmented areas that appeared in the first few weeks and persisted. These had such sharply demarcated outlines that they were considered as flash burns, probably from ultra-violet rays mainly. Development of what we have recognized as ionizing ray skin burn was not seen. There were a few early cases of bullous edema that may have been from gamma rays.

Epilation appeared on the scalp of 80% and occasionally more on one side than the other; axillary 16%, public 12%, eyebrows 8%.

Microscopically the hair follicles show distinct changes both in the epidermic and dermic coats. Early specimens were not obtained but in the fourth week the internal root sheaths cannot be identified, the external sheath (continuous with the malpighian layer of the spiderm) being continuous with the hair shaft. Vascularity of the papillae is reduced and the adjacent epithelium is atrophic. Pigment is irregularly clumped. Then the dermic coat shows thickening both of the

RESTRICTED

inner hyaline membrane and the cellular fibrous layer. The bottom of the follicle apparently undergoes a continuous shrinking in pushing the base of the hair toward the surface until regeneration begins with new cells over the papillae in a manner similar to ordinary hair replacement activity. There is also atrophy of the sebaceous glands, but this is also present when old hairs are replaced in the normal individual.

Some of the sweat glands are small, their cells occasionally vacuolated and pyknotic, and the basal membranes thickened.

Evidence of radiation effect on the peidermis is not definite. Third degree flash burns could be expected to have also some radiation effect, but interpretation is difficult. In a patient dying on the 5th day there is necrosis of a vessel wall and thrombosis. At the edge of a burn area there is hyperpigmentation in basal cells and chromatophores. Some thinning of epidermis, hyperkeratosis, ironing out of papillae, and hyperpigmentation of basal cells are found in the scalp (the most usual specimen).

Vascular and collagen changes are minimal.

BRAIN: Only secondary hemorrhagic or necrotic changes are found.

PITUITARY: Large basophilic cells with much cytoplasmic vacuolation appeared in 25% of the males dying during the third to sixth weeks. Because cells of this type are found in mammals after castration, they are known as "castration cells". In the second and third months large basophiles are found, only a few being vacuolated.

THYROID AND PARATHYROID: Not remarkable.

ADRENAL: During the first two weeks there seems to be a loss of lipoid in the cortex, but during the next months the cortex progressively loses the orange-yellow color and is distinctly thin. Microscopically most cells are granular rather than foamy and the atrophy is most marked in the outer zona glomerulosa (contrary to the expected). When foam cells are present, they are usually in the inner layer. The medulla is normal.

PANCREAS: No changes were found except for some mitoses in islet cells.

HEART: Epicardial petechiae are found within the first two weeks and there is microscopic evidence of some perivascular and rare muscle edema in the myocardium. These changes continue to be present during the second month when myocardial hemorrhages are also seen. After the second month no distinct irradiation changes are found.

LUNGS: Only the slight edema, perivascular or pleural, that appears in the first two weeks might be a primary radiation effect. Hemorrhagic and necrotizing pneumonia are common after the first weeks, as secondary lesions.

LIVER: Dr. Liebow of the Joint Commission, and Dr. Ono, Professor of Pathology at Fukuoka, were impressed with large nuclei of liver cells around the central veins and with congestive edema in and around the walls of the central vein; however, the presence of any irradiation effects is a moot point.

KIDNEY AND URETER: Except for hemorrhagic manifestation there are no primary lesions even in the flea-bitten organs.

BLADDER: During the hemorrhagic stage of the radiation disease, mucosal hemorrhages may result in necrotizing ulceration without evidence of leucocytic infiltration.

PROSTATE AND SEMINAL VESICLES: Not remarkable except for a rare neutropenic necrosis and the presence of a few morphologically normal spermatozoa.

TESTES: The testes show intense changes in almost every cadaver. As early as the fourth day when the parenchyma has a normal appearance grossly, the histologic sections present remarkable injury of the germinal epithelium, numerous cells of which are necrotic and free in the tubules and even carried into the rete testis. The number of mitoses is small. Sertoli cells begin to increase in number. Mature spermatozoa are found even in later specimens with no spermatogenesis. Apparently uninjured spermatozoa appear in the seminal vesicles. During the second month gross examination reveals little. A few necrotic germ cells remain but most have disappeared and phagocytic or infiltrating inflammatory cell activity is absent. A few bizarre cells still approximating the basal membrane appear to be spermatogonia. Sertoli cells are more numerous. The tubules now begin to shrink; at this time also the interstitial cells of Leydig are so prominent that some interpreters think they are hyperplastic. Some of the small interstitial vessels show the most marked vascular change of any part of the body; beneath the distinct thin endothelium is an eccentrically located mass of eosinophilic homogeneous refactile material that may almost occlude the lumen. This change is often best seen near the tunica albuginea and is present also in cases of the third and fourth months. Now also the interstitial tissue is less but still prominent. The basement membranes are quite thick, wavy and acellular. The tubules, now more atrophic, are often hyalinized. Elsewhere Sertoli cells have replaced the germ cells, which are rare. During the third and fourth months it must be remembered that the state of nourishment is poor and that specimens from the Dachau German prison camp have been described as showing similar testicular changes.

OVARIES: Changes here are much less striking. Gross changes, except as part of the hemorrhagic phenomena, are absent, even to the presence of a well

developed corpus luteum of pregnancy seen about the end of the first month after irradiation. Histologically, primary ova are usually present and only occasional specimens have a few atretic primary follicles. The absence of developing follicles is a usual condition. There are no corpora lutea and the "resting phase" of the endometrium reflects this. Amenorrhea was distinctly increased in Nagasaki and a significant number of abnormal births and increased death rate of the mothers in relation to distance from the explosion was found there.

GASTRO-INTESTINAL: This tract is among the first to show gross lesions. Even before hemorrhagic manifestations the cecum or colon, particularly, may present a widespread change marked by swelling, greenish and yellowish-grey coloration and induration of the mucosa, sometimes with a diphtheritic membranous effect, and with much submucosal edema. Later mucosal hemorrhage may institute another cycle of similar change in the stomach or intestine. This change may begin with ulceration of the mucosa at the site of the hemorrhage and progress to an ulcerative or pseudomembranous process. Again in the third and fourth months an enteritis most usually in the large intestine but sometimes affecting also the small intestine or occasionally the stomach may be the most prominent lesion at autopsy. In the small intestines only the tips of the folds may be first involved. These first look like they have been dipped in boiling water and then become greenish or yellowish-grey. Fewer specimens of small intestine have a diffuse mucosal process.

The large intestine in this late stage usually has a more widespread process that may extend from the ileocecal valve to the rectum the involvement being most prominent in the distal portion. The thickened wall is a feature. A diphtheritic membrane and ulceration are sometimes present so that the morphology is quite similar to that of bacillary dysentery. It seems that much of the process here is not only change from irradiation of the sensitive intestine but to the lowered local ability to cope with omnipresent intestinal microorganisms and, probably, more important, to the lowered antibiotic capabilities of the blood.

Microscopically the epithelium early contains extremely bizarre cells with giant hyperchromatic nuclei and multipolar mitoses. The swelling is seen to be from edema and the peculiar coloration from the absence of infiltrating leucocytes. Late cases show areas of mucosal ulceration with much fibrin, few leucocytes, and in the remarkably edematous submucosa quite a few histiocytes, a few lymphocytes and occasional eosinophils. Plasma cells of the lamina properia remain numerous.

SPLEEN: The lymphoid elements here react to radiation as in the nodes. Early the spleens are usually small, but occasional ones show the very early swelling reaction. On section they are dark red, little scrapes on the knife, the follicles are indistinctly seen and the trabeculae are somewhat prominent. Besides the near absence of lymphocytes, large monoclears are increased and there is erythrophagocytosis and hemosiderin deposits. During the second month the spleen is small and follicles are absent. There seems to be a syncitial reticulum around the follicles in which the slight lymphocytic content of the organ is seen. Atypical large mononuclears are found in about 25%. Through the fourth month there is still some atrophy. Occasional germinal centers appear and lymphocytic content shows some evidence of recovery.

LYMPH NODES: The high sensitivity of lymphoid tissue to ionizing radiation results in tremendous atrophy seen as early as the third day. Lymphocytes almost disappear leaving a lacy framework that is quite spectacular histologically. A similar picture is found in the tonsils and other lymphoid tissue. Changes in the germinal centers may be necrobiosis but a departure from normal is not marked except when the germinal centers disappear as they did in three-fourths of the first two weeks' deaths. The early gross appearance of human nodes is not known but bombed animals showed some enlargement, softening and a paler color. By the second week large atypical mononuclear cells, considered by one observer as lymphoblasts, appear; these cells logically could be pathologic forms whose sensitive nuclear chromatin was deformed by the radiation. About the fifth week, the nodes are usually large and almost devoid of lymphocytes and germinal centers. Bizarre large cells are more numerous. Plasma cells, eosinophiles and mast-cells along with increased numbers of reticulum cells are present. Lymphocytes are more numerous in the fourth month but still reduced.

BONE MARROW: The cellular picture of irradiated bone marrow is tremendously changed during the first week after the bomb explosion. There is almost total disappearance of blood forming elements excepting small islands of erythropoiesis, which are less sensitive. By the end of the week reticulum begins to proliferate and differentiates first into lymphocytes and plasma cells rather than myeloid cells. This type of differentiation is predominant until the fourth week when myeloid differentiation is seen. Most marrows of those dying before six weeks are hypoplastic but a few show hyperplasia with maturation arrest. Most of the fatal cases of the third and fourth months show hyperplasia, which in the femur is grossly evident as pink marrow extending from a third to half of the shaft; in these the maturation defect decreases and more neutrophiles are found in the peripheral blood and in infected tissues. A few of these older cases, however, show aplasia with pink gelatinous femur marrow. Some grossly appearing hyperplastic marrows are really hypoplastic, the pink color coming from dilated blood vessels. Whatever the marrow picture there is usually a profound leukopenia at some time in those patients dying in the first six weeks. Later leukopenia does not persist and even those who die develop leucocytosis except for the few that have aplastic marrows.

SECONDARY EFFECTS OF RADIATION OF RETICULO-ENDOTHELIAL SYSTEM: Hemorrhagic lesions, and leukopenic necrosis affect the irradiated body about the end of the first month, mainly. The pharynx and its connections, the gastro-intestinal tract, the respiratory organs and the skin manifest both changes; in addition, particularly the urinary tract, mesothelial linings, and muscles, but including all body soft tissues, show petechiae, purpuric patches or large ecchymoses. These changes are outstanding clinically. Severity depends on the location of the larger hemorrhagic lesions. Hemorrhages in the linings of the pharyngeal regions, of the bowel or of the urinary tract give signs externally. Large submucosal hemorrhages as well as petechiae appear in the kidney pelves and in the bladder and sometimes in the ureters. Hemorrhages breaking through epithelium of bacteria-laden surfaces often initiate the neutropenic necrotizing lesions which in the pharynx are similar to the well known acute agranulocytosis. Ulcers sometimes extend on to the

tongue, the gums, buccal membranes, lips, and even the skin to give the picture of noma. Such ulceration also begins independent of hemorrhage. It is probable that bacteria ordinarily non-pathogenic may cause serious consequences on the loss of sufficient reticulo-endothelial reserves. Ulcerative lesions throughout the stomach and intestinal tract are on a similar basis, as indeed, it appears that many of the diffuse mucosal changes may be. The necrotizing pneumonia appears to be a part of this picture. There is little leucocytic reaction in these lesions, which overwhelm the patient and lead to death. A case history example is as follows:

This 29-year-old man was at distance of 0.7 km. He was outdoors a few paces from a concrete building. He was struck by a falling roof which inflicted slight injuries of the head and neck. There was nausea on 6 August and on the same day he vomited between 20 and 30 times. Malaise began on 6 August and lasted until the 10th, accompanied by anorexia. He again experienced malaise beginning with 21 August until time of death. Anorexia appeared 4 days after the second onset of malaise. There was epilation and gingivitis on 21 August, which persisted. The gingivae began to bleed on 30 August. On the 25th there began purpuric manifestations and there was evidence of tonsillitis the same day. Both of these symptoms lasted until death on 1 September. There was high degree of fever between 24 August and time of death and there was cough and sputum beginning on the 25th, with a hemoptysis on 30 August.

LABORATORY DATA:	RBC	Hgb	WBC
24 August	3.95	78	370
26 Sugust	5.64	80	450
29 August	4.19	65	200
30 August			220

The urine examined on 29 August, was positive for albumin and negative for sugar. No statement is made concerning sediment.

Sections of marrow in this patient, derived apparently from a cavity of a long bone, are hyperplastic, showing vascular adipose tissue crowded by very large numbers of young myelocytes. Mature polymorphonuclear leukocytes and even stab cells are rare. There is an occasional megakaryocyte. Occasional cells are found in mitosis. A few small cells of shrunken nuclei thought to be normoblasts also are found. Other important lesions at necropsy were petechiae of skin, epilation of scalp, focal necrosis of pharynx, tongue, tonsils and larynx, necrotizing gingivitis, an absess in the region of the right mandibular joint, necrotizing and hemorrhagic aplastic pneumonia, minute hemorrhages of gastrointestinal tract, trachea and renal pelvis.

PUBLIC HEALTH ASPECTS OF ATOMIC BOMB

Dr. Edwin G. Williams

It is indeed hard to think of the group as other than made up of individuals. It is an equally difficult concept to regard the individual human being without giving some consideration to the fact that he is a member of society. Public Health is that branch of medicine which deals with the relationship of the individual to the community and of the community to the individual.

The concept of public health is fluid and changing. Some of you remember the "Hygienic" era with its individual, collapsible, and leaky drinking cups: The "Sanitary" era with its abolition of the roller towel and the introduction of comfortable toilet seats: Perhaps most of you recall the "Prophylactic" era and the lady-friend who said her boy-friend had to go by a "station" to get a toothbrush. At the present time the emphasis is shifting from the negative - absence of disease: to the positive - presence of health.

Through it all permeates the philosophy of a general benification of the environment in which we live. The mere vastness of the scope of public health carries with it the danger of loss of perspective. This leads to the expending of undue effort on relatively unimportant aspects at the expense of things that should have priority.

Public health finds its classical role in the control of the transmitting agent. The word "control" is perhaps an unhappy one because of its public connotations. While reading that most fascinating autobiography "As I Remember Him", the thought occurred to me that I would be much better educated if I were to read also the traffic cop's opinion of Dr. Zinzer.

ASSESSMENT OF HAZARD

You, as medical officers, will be called upon to assess the hazard and to advise the command accordingly. You will probably have the necessary physical findings supplied to you. The presence or the magnitude of the hazard will depend upon many factors. You will frequently need the advice of not only the physicist (Engineer Corps or other specially trained line officer) but also of such disciplines as meteorology, geology and oceanography. In damp or rainy weather there is little dust, therefore ground contamination will not be as serious from an internal (inhalation) standpoint as during dry conditions.

In assessing the hazard, keep ever in mind that external radiation is more easily dealt with than internal radiation. You can guard against external radiation, but you must prevent internal radiation. Decontamination of the skin, though at times difficult, is far easier than decontamination of the thyroid, lungs or bone.

Personnel monitoring devices are of many kinds. Most usual at the moment are:

a. Film meters
b. Pocket ionization chambers
c. Pocket electroscopes
d. Geiger-Mueller tubes

Area monitoring instruments include:

a. Geiger-Mueller tubes
b. Electroscopes
c. Ionization chambers
d. Film meters
e. Dust or air sampling devices

These will be described to you later.

Let us assume that an area is contaminated. It may be contaminated with:

(a) Alpha emitters. This will constitute a most serious hazard if such substances gain access to the interior of the body. There will be no external radiation hazard.

(b) Beta emitters. This will constitute both external and internal radiation hazard - more serious per unit if internal.

(c) Gamma emitters. Here again we must think of both external and internal hazards: - more serious from a practical standpoint as an external hazard.

(d) Combination. Contamination will almost certainly not be limited to one of the above types of radiation.

ADVICE AS TO EATING FOOD IN THE CONTAMINATED AREA

It must be assumed that all food found in the area is dangerous. The food may contain induced radioactivity. This is unlikely to be present in dangerous quantities because of generally unfavorable reactions, and because of short half life of many substances. You as medical officers will, however, probably be called upon to give an opinion in these matters.

The food may have deposited radioactivity and this is most likely to be the case. Here, as in many cases, decontamination will be impractical or impossible. Canned or otherwise protected foods may be eaten only after careful inspection and rigorous adherance to detail of removing the food from the protecting agent.

If it is necessary to bring food into the area, a high degree of laboratory precision must be maintained in the handling of it.

ADVICE AS TO THE DRINKING OF WATER IN THE CONTAMINATED AREA

If possible, no water should be drunk in the area. If canteens are to be taken in, troops must be drilled in the matter of drinking without contaminating the mouth of the canteen. Larger amounts of water may have to be taken in - this greatly increases your responsibility.

The water in an area may be contaminated as a part of the general area contamination or may have become contaminated upstream. What can be done about decontamination?

1. PHYSICAL

(a) Boiling: This is obviously useless or may be harmful. It is unlikely that all contaminants will be volatile. Boiling will then serve only to concentrate and increase the contamination.

(b) Storage: This time-honored and often successful method of water purification, though useful for short lived isotopes, is impractical for field operations and of little benefit for long-lived isotopes.

(c) Filtration: Here we may be somewhat more hopeful - especially hopeful that experimental work will be done and the value of filtration as can be applied in the field be established.

2. CHEMICAL

In the sense of applying the usual water purification techniques (chlorine), this is obviously useless.

3. PHYSICO-CHEMICAL

If we can combine precipitation and filtration, we may greatly reduce the load on precipitation. Here again methods must be developed that are applicable in the field.

PREVENTION OF DISSEMINATION

Prevention of dissemination by personnel is often of great importance. The underlying principles are always the same and may be illustrated by a discussion of the evacuation of an area.

a. Decontamination center for area evacuation.
   (1) Clothing change and bathing facilities
   (2) Laundry (decontamination) facilities
   (3) Monitoring facilities

b. On entering contaminated zone.
   (1) Remove all clothing (or outer clothing)
   (2) Leave all smokes and eats behind
   (3) Go to "dirty" side and put on work clothes (overalls, hat, gloves and boots)

c. On leaving contaminated zone.
   (1) Remove hat and gloves
   (2) Wash face, neck, and hands thoroughly five times with soap and water
   (3) Remove remaining clothing
   (4) Soap and thoroughly wash entire body five times
   (5) Go to monitoring room (between shower and clean side)
   (6) With permission of monitor go to clean side and put on original clothing.

MEDICAL RESEARCH AT OPERATION CROSSROADS

Captain R. H. Draeger, USN

It is my intention, at this time, to briefly review the activities of the Naval Medical Research Section of Joint Task Force ONE, Operation CROSSROADS. My remarks will necessarily be of a general nature. More in the way of details concerning the pathology and hematology of the Bikini animals will be given later by Commander Cronkite and Lieutenant Ullrich.

The Medical Research Section was organized under the Director of Ship Material in January 1946 with the object to conduct experiments concerning atomic bomb effects upon biological materials, including animals and endeavor to interpret the results in terms of effects upon personnel.

Early in the planning of the work of the Research Section, it became evident that a separate ship would be required to transport and house the large number of laboratory animals needed to evaluate the bomb hazards. A ship was requested and the USS BURLESON APA-67 was assigned to the section as an animal and laboratory ship. The holds were converted into large animal quarters and troop spaces into a rat room and laboratories.

The staff of the section consisted of 22 scientists including 5 Army and 11 Naval officers as well as civilians. Its nucleus was selected from the staff of the Naval Medical Research Institute which also served as the center for planning and for the collection of material. Of the 96 enlisted men, 40 were selected for their farm experience.

The decision to use animals in the Bikini experiments brought an avalanche of protest in the form of hundreds of letters to Admiral Blandy. The American Humane Association requested that animals not be used; failing this, they requested that they be allowed to furnish a humanely trained veterinarian. This request was also refused since the services of a highly competent Army veterinarian, Captain R. P. Wagers, whom some of you no doubt know, had already been obtained.

Goats, pigs, and rats were chosen to determine the probable effects of the atomic bomb explosions upon personnel. These species were selected because of their ability to withstand tropical conditions and because of the similarity of certain of their reactions to radiations to those observed in man. Dogs were excluded for obvious psychological reasons and the fact that it would have been impossible to obtain the number of animals in the alloted time. Experience has shown that pound dogs are apt to be diseased and therefore make unsatisfactory laboratory animals. A few guinea pigs were included for comparative purposes. Mice of strains differing in their susceptibility to cancer also were exposed. The animal colonies totaled 200 goats, 200 pigs, 5,000 rats, 120 mice and 60 guinea pigs. A wide range of other biologic material such as insects, bacteria, fungi, seeds, antisera, toxins, bacteriaphage, vitamins, and hormones were included. In addition, a wide variety of

inorganic substances such as medicinal agents, soils, and selected elements were included to determine whether or not they would become dangerously radioactive. The medical and dental units of most target ships were kept intact in order to evaluate blast damage.

The research activities of the section were divided into 6 categories: Statistics, biophysics, pathology, radiobiology, hematology and photography. Specific research projects were assigned covering the various aspects of blast and irradiation injury caused by an atomic bomb explosion.

The USS BURLESON sailed from San Francisco on the 1st of June 1946 arriving at Bikini on the 15th of June.

Twenty-two target ships were selected for the placement of test materials as representative of type at varied distances from the center of the target. These ships lay along several radii to permit observation of wind and other effect . Locations ranging from the signal halyards to the steering engine room insured that every degree of exposure of personnel aboard ship would be represented.

The placement of test materials consisting of hundreds of items at each target ship location, presented a difficult problem. It was finally decided to use canvas packets containing the test items, well padded and enclosed in cardboard mailing tubes. These packets survived surprisingly well. A few caught fire, and burned, due to intense thermal radiations, but the majority were retrieved quite intact with little damage to their contents.

Target ship officers were assigned the responsibility of placement and recovery of animals and other test materials. Having their own boats and crews they were able to make repeated trips to their assigned target ships and prepare the chosen localities, particularly, for the animals.

In order to keep the exposure of animals on target ships at a minimum, they were collectively placed aboard target ships two to three days prior to Test ABLE and distributed to the selected locations on the day prior to the test. Photographic records were made of all animals and animal locations.

Our greatest concern was the possibility of postponement of the test on account of bad weather since some of the animal locations were so unfavorable as to make survival doubtful if exposure were too long continued. Several days' supply of food and water was provided.

Fortunately, the Test ABLE bomb was detonated on 1 July according to schedule. It was possible to reenter Bikini lagoon on the afternoon of ABLE day and begin our work of recovery of the animals which was completed on the following day.

About 90 percent of the animals were recovered alive from the target ships following Test ABLE.

Those test animals which were exposed to appreciable amounts of radiation, developed much the same signs and symptoms of radiation sickness as were noted in the Japanese survivors of Hiroshima and Nagasaki. The first animals to die showed atrophy of lymphoid tissue, often with ulceration of the tonsils. Later there appeared a tendency to hemorrhage and severe enteritis, frequently so marked as to result in complete necrosis of the mucosa and submucosa.

An attempt was made to treat some of the animals; multiple blood transfusions and penicillin were given. Autopsies were performed on all animals that died and their tissues preserved for microscopic examination.

By the 20th of July the study of the Test ABLE animals was overshadowed by the preparation for Test BAKER. Target ship officers with their small boats and crews again went into action and animals and test material were distributed. Most of the animals, however, were purposely used for Test ABLE. The probability of radioactive contamination of the ships and consequent delay in recovery made it appear unwise to expose many animals in Test BAKER. Only pigs and rats were used.

An attempt was made to provide about 10 days' supply of food and water for these animals so that they would survive, even though their recovery was considerably delayed.

On the 25th of July at a distance of 10 miles, on the USS BURLESON, we witnessed the magnificent sight occasioned by the detonation of the Test BAKER bomb. Ten million tons of water rose in a towering column, 2200 feet in diameter, to a height of 6000 feet. When the condensation cloud cleared from the surface of the lagoon, we were indeed presented with an amazing sight. The column of water had spread out into a mushroom form which gradually broke up and rained radioactive contaminated water upon the target ships. This radioactive contamination was so serious that 5 days elapsed before all of the Test BAKER animals could be recovered.

Some of the difficulties in recovering the Test BAKER animals may be of interest. A tug was used to rapidly approach the radioactive target ship, keeping all personnel below deck or behind the superstructure of the tug. An organized group of about 20 men then went to work. As soon as the tug was made fast, the target ship was boarded by a monitor who remained for a few moments only. He was followed by two men who opened the hatches, after which men went aboard, in pairs, bringing out a pig in a bag and two rat cages. The whole operation took about 45 minutes and the tug was freed by cutting the lines.

These animals received a much heavier dose of radiation than animals in comparable positions in Test ABLE. They were exposed not only to the initial radiation, but also to prolonged radiation due to the contamination of deck and bulkhead surfaces with radioactive material. As a result of this intense radiation, many of the pigs died before they could be recovered and the remainder died soon after. The rats being about three times more resistant to radiation than pigs, fared better and some of them are still alive.

Let us now briefly review the nature of atomic bomb injuries, their classification and the conclusions which may be drawn from the animal experiments at Bikini.

The explosion of an atomic bomb is associated with the liberation of an amount of energy equivalent to 20,000 tons of TNT. This energy is divided between gamma radiation and the motion of nuclear particles and light atoms. The harmful effects upon personnel depend largely upon the mode of transmission of this enormous amount of energy. All of the three states of matter; gas, liquid, and solid are capable of harmfully transmitting this energy.

If the explosion occurs in air, an air pressure wave results which travels outward at approximately the speed of sound. Air blast injury to personnel may be caused by direct or indirect action. An air pressure wave of about 30 pounds per square inch, in the case of ordinary high explosives, will cause fatallung hemorrhage by the direct pressure effect upon the chest. Indirect injury is likely to be caused by the individual being struck or being thrown against objects in the vicinity.

In the case of an underwater explosion, a water pressure wave is produced. Water blast injury to immersed personnel results when this pressure is around 500 pounds per inch. Fatal lung hemorrhage or intestinal perforation are the result.

Solid blast injury occurs when energy is transmitted through solid matter such as a ship's structure. In the case of an underwater explosion, energy is transmitted to a ship's structure in the form of a highly damped flexion wave causing rapid acceleration of decks and bulkhead surfaces. Individuals standing on or in contact with such surfaces will receive injuries such as fractures of the lower extremities.

Blast injuries produced by an atomic bomb are essentially no different from the blast injuries produced by an ordinary bomb except in magnitude.

The explosion of an atomic bomb results in an extremely high temperature comparable to that of the sun. Intense thermal radiations are, therefore, produced capable of causing flashburns of exposed individuals. This type of injury of the face and arms was common among the Japanese at Hiroshima and Nagasaki.

Excessive keloid formation followed the healing of these burns and was thought to be characteristic of atomic bomb thermal radiation in combination with gamma rays. However, they are now considered to be due to malnutrition and inadequate treatment with prolonged healing due to secondary infection rather than any specific effect of the atomic bomb. The Bikini animals offer no clue to this problem. Few of the animals were burned due to the protective value of fur. The burns which did occur were around the eyes, mouth, tips of ears and tail and were first or second degree. Healing took place without excessive sear formations.

The unique hazard of the utilization of atomic energy is the production of ionizing radiations chiefly alpha, beta, gamma rays and neutrons. These may be produced at the time of fission or later from fission products.

Biologically, the harmful effects of these radiations are due to ionization which is the liberation of free electric charges, positive and negative, within living cells. Each ion produces, on the average, a potential difference of about 30 volts which is sufficient to cause the disruption of chemical bonds. Since 1. produces about $4x10^9$ ions per cubic centimeter of air and much more in tissue, roughly in proportion to density, it will be seen that a serious interference with the function of living cells is the result. The cells of the body vary greatly in their susceptibility to the effects of this ionization. The stem cells of all cellular elements of the blood, particularly lymphoblasts, and the sex cells are the most sensitive, gastrointestinal epithilium is moderately sensitive, while heart muscle and nerve cells hardly respond at all. In general, it may be stated that the activity of a cell is directly related to injury by ionization.

The more active a cell, the more injury produced. The prophase of a dividing cell is particularly sensitive.

Gamma rays are the most penetrating of the ionizing radiations, requiring from 1 - 2 inches of steel to reduce their intensity by one-half. The same reduction in intensity will be produced by 2 - 300 yards of air. The lethal dose of gamma radiation in man is from 300 - 500 r. The presently accepted permissible dose of radiation is .1 r per day.

Neutrons are produced in the so-called chain reaction of fission. These are uncharged particles of about the same size as the hydrogen nucleus, are less penetrating than gamma rays and cause damage to living cells by ionization.

Beta particles, protons and alpha particles are the least penetrating of the nuclear particles. Externally their effects are largely exerted upon the skin. Internally in the form of fission products they cause injury by ionization.

The products of fission are a series of stable and radioactive elements, the latter predominating. These radio elements are also a source of alpha, beta and gamma rays.

Gamma rays and neutrons are the cause of radiation illness. The severity of this disease depends upon the amount of radiation received. When the dosage is overwhelming, that is over 10,000 r., shock-like symptoms develop in a few hours with death occurring in 1-2 days. With a dose of 500 to 1000 r, symptoms may be delayed for several days, death resulting in from 1 - 3 weeks due to lowered resistance to infection and hemorrhage. A dose of radiation of from 1 - 200 r will be followed by delayed symptoms and slow recovery.

Blast injuries accounted for the death of about 10% of the large animals. This figure is not very informative, however, since many of the animals were completely outside the air blast injury range. As would be expected, indirect injuries were the most common. It is of interest to note that the air blast wave from an atom bomb caused injury at a lower pressure than an ordinary bomb due to the prolonged duration of the peak pressure.

Ionizing radiations accounted for the death of about 15% of the Test ABLE animals. Practically all of these deaths occurred within 30 days. The results of therapy, multiple blood transfusions and penicillin suggests that beneficial results may have been obtained. There appears to be no definite sterility among the surviving animals. One pig, number 311, a female, placed on the Sakawa which sunk and is alleged to have been found swimming in the lagoon hours afterward, had, however, failed to produce offspring.

There was no opportunity to conduct water blast experiments and no injuries of this type were encountered.

There were no deaths directly caused by solid blast; however, a number of rats were lost in Test BAKER due to the destruction of their water supply by shock.

If a deep underwater atomic bomb test had been held, as was planned for Test CHARLIE, both water and solid blast injuries would no doubt have been frequently encountered.

Atomic bomb thermal radiations, outside the lethal blast range, are a source of superficial injury but shielding can be readily provided.

In order to evaluate the protective value of clothing, samples of cloth of various military clothing materials were exposed to atomic bomb thermal radiation upon swatchboards. As was noted in Japan, white cotton or wool materials gave the best protection; a single layer of this material ordinarily being sufficient. Flashburn cream, as developed by both the Army and Navy, was similarly evaluated and found to be effective.

The section also attempted to make a wide variety of physical measurements for correlation with animal findings. These included gamma ray, neutron, thermal radiation and blast pressure. The latter, however, was a failure since the gauge heads were left in San Francisco.

Grain, insects and seeds and soils were exposed through the cooperation of the Department of Agriculture. No findings regarding the grain insects are as yet available. Cotton and corn plants grown from exposed seeds show mutations such as mottling of leaves and abnormal chromosomes and mitotic figures. There was no evidence of abnormal growth of plants in exposed soils.

Neurospora exposed to a heavy dose of ionizing radiation are being studied under Dr. Beadle at the California Institute of Technology. To date, about one tenth of the material has been studied and about 200 mutants isolated.

Routine clinical biochemical examinations were made on radiation ill animals. These findings were essentially negative.

Neutron induced radioactivity may be a hazard to personnel remaining upon ships having been subjected to a nearby atomic bomb explosion. Medicinal agents containing sodium, phosphorous, bromine, arsenic, antimony, etc., may become dangerously radioactive if exposed at comparatively close range and should be checked for radioactivity before use. Such items as soap, washing soda, table salt, baking powder should also be checked for similar reasons. Due to the high sodium content of glass bottles, these may show considerable radioactivity unrelated to their contents. Thus an external survey of medicinal supplies may be misleading.

THE DETECTION OF OVER-EXPOSURE TO IONIZING RADIATION BY PHYSICAL EXAMINATION AND CLINICAL LABORATORY PROCEDURES.

Lt. Cdr. E. P. Cronkite, MC USN

In past years the potential sources of exposure to radiation were few. Now there are numerous sources of exposure: (1) diagnostic and therapeutic x-ray units; (2) industrial x-ray machines; (3) radium and its degradation products; (4) cyclotrons; (5) the chain reacting-pile; (6) radio isotopes produced by the pile that are being used in tracer studies, therapy and as sources of heavy radiation for biologic systems; and (7), the atom bomb and its fission products. It is immediately apparent then that the medical profession and public health authorities must take cognizance of the sources of exposure and endeavor to establish means of prevention and recognition. The former is obviously of paramount importance and the latter should never occur under normal well controlled conditions.

How is prevention accomplished? Prevention is accomplished by careful measurement of radiation intensities by personnel film badges, ion-meters, and mobile counters whenever radiation may be present. Personnel should be followed closely for presence of radioactive isotopes in nasal secretions, excreta, and on skin. Where radioactive gases may exist, expired air should be monitored. In brief, overexposure to radiation should never occur. Signs and symptoms are late. Conditions conducive to excessive exposure should be detected by physical measurements before cellular damage is sustained. However, accidents may occur; protective regimes may fail; and in the advent of atomic warfare many will be overexposed to ionizing radiation regardless of precautions.

What are the signs and symptoms that may develop? Medical history reveals a sad story of scientists learning of the hazards of radiation by personal experience. The incidence of radiation burns, ulcers, and superimposed cancer in the early physicists and radiologists proves the necessity for careful supervision. The incidence of aplastic anemias in x-ray technicians again proves the necessity for supervision. The greater incidence of leukemia in physicians at large and in radiologists in particluar, points out the possible hazard of long continued minimal radiation and potential harmful cumulative effects.

The effects of over-exposure must be divided into the acute and chronic overexposures. The exposures may result from any type of radiation externally or internally applied. The overall picture will be a function of the amount, rate of delivery, and depth dosage.

The acute over-exposure may be defined as a single total body exposure of more than 50 R delivered within a period of a few hours. The signs and symptoms that may develop vary with the penetrating ability of the radiation and the amount absorbed.

If one receives a large amount of soft x-ray or beta radiation to the skin, one may develop anything from a slight erythema to massive vesicle fromation and destruction of the full thickness of the skin. The injury will resemble thermal burns to a certain degree.

Similar cutaneous injuries can be caused by more penetrating radiations, but in addition one will develop other signs and symptoms as follows: There may be diarrhea, nausea, vomiting, headache, anuresia, purpura, and last, secondary infections due largely to the leukopenia.

The latent period before the development of symptoms, the frequency and the severity of the above, will vary with the amount of radiation absorbed. The latent period will be inversely proportional to the amount of radiation absorbed. The symptoms and signs will be directly proportional to the amount of radiation received up to the point that the latent period becomes so short that there is insufficient time before death for the entire picture to develop.

The above signs and symptoms of acute over-exposure to radiation of a penetrating radiation are not constant and may vary. By and large, the best biologic index of over-exposure to radiation is the blood. However, one must remember that with the less penetrating external radiation, the blood changes are less marked and may be absent.

The blood changes following acute exposures are fairly uniform, if the exposure is over 100 RU. The changes with smaller amounts of radiation may be missed, if careful, repeated observations are not made at frequent intervals. There is, however, a uniform response to amounts over 100 RU that is roughly proportional to the amount received, up to a maximum response in the absolutely fatal dose range. The response is a prompt decrease in the total lymphocyte count that is detectable within a period of a few hours. The decrease attains a maximum within seventy-two hours or so, recovery may or may not occur, depending upon the amount received. Another quite constant phenomenon is an initial neutrophilic leucocytosis due to mobilization of the neutrophiles and perhaps accelerated maturation and release from the bone marrow. It is reported by some workers that the leucocytosis does not occur with massive amounts of total body radiation, over 500 R in some species.

The changes in the numbers of platelets and red cells and morphologic changes of the leucocytes are less certain and vary so much with the dose and the survival time that they will not be considered in this lecture.

The acute blood changes can be summarized as follows: If no drop in the total lymphocyctes is detectable in the first 72 hours, usually the first 24 hours, one can state with certainty that the exposure to radiation has been small and that serious illness will almost assuredly not occur.

The chronic over-exposure to ionizing radiations presents an entirely different problem. The changes that occur are insidious and progressive. In fluorescopists, radiochemists, or radium handlers, the following may develop on the hands: (1) an increased brittleness of the fingernails, (2) an increased tendency to develop longitudinal ridges, (3) loss of integrity of the fingerprint by patches of atrophy, (4) impaired sensation, (5) pigmentation. However, by and large, as with the acute exposure, the blood is the best biologic index of over-exposure to radiations.

In order to evaluate the blood picture, one must establish some sort of norm for the average human being. This is most difficult for the human blood is very variable. Leucocyte counts of 4,000 to 16,000 are occasionally found in people who are in every other detectable respect perfectly healthy. The differential counts vary considerably with age and may remain abnormal for many months following infectious mononucleosis. Red blood counts, hematocrits, and hemoglobins similarly vary to a great extent. The old time honored normal values for hematologic measurements probably include 80 percent of a given population within the upper and lower limits of the ranges given in standard textbooks. The 20 percent of normal individuals outside of this range will cause considerable consternation in a radiological safety program.

How does one determine blood changes that may be due to chronic over-exposure? First, one should have base line counts on all who could conceivably be exposed. The counts should be done at monthly intervals. Notations on the occurrence of colds, infections, etc., should parallel the blood records. One is then in a better position to detect relative changes in the blood of a given individual.

What are the hematologic criteria for presumptive evidence of over-exposure to radiation? The following are offered and have been based on standard normal values, personal experience, and possible changes that have been described in the literature:

1. A depression of the WBC below 4,000

2. An elevation above 15,000 with an absolute and relative lymphocytosis

3. A relative lymphocytosis with a low total count that return to normal following removal from exposure

4. An increased mean corpuscular volume (MCV), a shift in Price-Jones curve to the right, an increase in the mean corpuscular diameter (MCD).

5. A reticulocytosis over 2 percent.

6. An erythrocytosis
   a. Red blood count over 5.1 mm/cmm
   b. Hemoglobin over 18.0 gms. %

If any of the above six criteria develops in an individual who has a definitely established base line and who is associated with radiation, it is presumptive evidence of over-exposure to radiation until proved otherwise.

Many other phenomena have been suggested as hematologic evidence of over-exposure. Changes in blood coagulation, prothrombin times, platelets, and morphologic changes in leukocytes (toxic granules, basophilic staining, and vacuoles, the toxic triad) have all been offered. It is exceedingly difficult to evaluate the importance and the diagnostic value of these changes.

The actual evaluation of chronic exposure of any given individual in terms of changes within the blood cannot be done with absolute certainty. The following procedure may yield helpful information:

(1) Remove the suspect from all possible sources of radiation.

(2) Study breath, excreta, nasal swabs, etc., for the presence of radioactive isotopes doing differential radiation counts.

(3) Study the blood at weekly intervals and compare with the base line counts.

(4) Endeavor to eliminate other factors such as infectious mononucleosis, infectious lymphocytosis, virus diseases, benzol poisoning, heavy metal poisoning, etc.

(5) Examine others that may have been similarly exposed and compare the base line mean leukocyte counts with the present mean counts for the group.

The fifth maneuver may yield more information than all the other blood changes combined. If one can demonstrate a statistically significant difference in the means of the leukocyte counts of a group of people during known chronic exposure as compared to the base line means, particularly if the difference is a downwards trend, one can then state with some assurance that there has been chronic over-exposure to radiation. One can state that the development of the above presumptive signs in the mean leukocyte counts for a group must be considered as evidence of over-exposure until proved otherwise. The main bulwark of protection from radiation must remain physical control and measurement by established monitoring procedures.

EVALUATION OF THE FIVE ATOMIC BOMBS

by Major Maxwell Dauer, MSC

1. INTRODUCTION:

The atomic bomb has added a new terror and devastating force to the arsenal of war, and has increased many fold the number of potential casualties which the Medical Department might be called upon to handle in the event this weapon of destruction is employed in future warfare. National security makes it imperative that each Medical Department officer understands the salient fundamental facts regarding the medical effects of an atomic explosion. It is essential, therefore, that pertinent medical information on the problem be disseminated to the personnel who will be charged with the responsibility of caring for the sick and wounded resulting from the use of atomic weapons.

2. EMPLOYMENT OF THE BOMB:

The atomic bomb is primarily a strategic weapon and the choice of target and method of employment requires evaluation of a considerable number of factors. Thus far, five atomic bombs have been detonated. Three of the bombs were detonated under test conditions, while the other two were exploded over the cities of Hiroshima and Nagasaki.

The first bomb was set off under experimental conditions from the top of a tower at the Trinity Site, Alamogordo, New Mexico, on July 16, 1945. The second bomb was dropped on August 6, 1945, from a high-flying B-29 bomber on the target city of Hiroshima. Over four square miles of the city were instantly and completely devastated; 66,000 people were dead or missing and 69,000 were injured. Three days later, on August 9th, another B-29 dropped an atomic bomb on Nagasaki, totally destroying one and one-half square miles of the city. The number of persons dead and missing in Nagasaki totalled 39,000 and 25,000 injured. The fourth atomic bomb was dropped from a high altitude by a B-29 on target vessels assembled in Bikini lagoon on July 1, 1946, and the fifth was detonated underwater on July 25, 1946. Test animals placed in various locations on the target vessels yielded important data on the bomb effects. This work was done under the supervision of the Naval Medical Research Center and periodic reports have been released. A considerable mass of valuable medical data has been obtained. Much of this information is in the process of evaluation and analysis and will be published soon. In addition, a comprehensive report will be released in the near future based upon the findings of a Joint Commission report on the medical effects of the bombs on Hiroshima and Nagasaki. Considerable information on the entire subject of atomic energy, including medical effects, has already been published.

Evaluation of the Five Atomic Bombs

3. ACTION OF THE BOMB:

When a mass of fissionable material equal to or greater than a critical size is assembled, a violent detonation will occur when the fissionable mass is exposed to a neutron source. The sub-critical masses of fissionable material must be brought together rapidly in such a manner so that the critical mass will carry out a chain reaction and detonate. The bombardment of each fissionable nucleus by neutrons results in the formation of two fragments known as fission products. The nucleus does not split into the two same fragments each time. Therefore, as a result of the fission process and chain reaction of fissionable material, many radioactive substances (fission products) are liberated. The sum of the masses of these fission products will not equal the original mass of the split nuclei. The difference between the fission products formed and the original mass represents the mass of the nuclei that has been converted into energy in the form of blast, heat, light, X-rays, gamma rays and released nuclear particles.

The detonation of the atomic bomb generates a crushing wave of high pressure. The bomb also liberates an enormous quantity of electromagnetic radiations and neutrons. The electromagnetic radiations include infrared, visible light, ultraviolet, X-rays, and gamma radiation. Thereafter, the fission products formed during fission process emit gamma rays and beta particles. The unfissioned bomb residue emits alpha particles. Substances bombarded by neutrons released at detonation, which become radioactive (induced radioactivity), may also emit nuclear particles and gamma rays.

A large fraction of the gamma rays is emitted in the first few microseconds of the atomic emplosion. Neutrons also accompany this reaction. The intensity of neutrons is negligible at a thousand yards, due to strong absorption in air. In an underwater burst, greater absorption occurs which results in induced radioactivity of the sea water. Of the constituents of sea water, only sodium is of any significance, and even this element is hazardous for only a limited period, due to its short half-life of 14.8 hours.

At detonation, practically all of the lethal gamma radiation is released and the remaining small fraction of the total dose is given off by the resultant fission products which rise rapidly in the bomb cloud. The column of radiating fission products and combustion material rapidly rise vertically into the air and begin to mushroom out when the temperature of the column is equal to the temperature of the surrounding atmosphere. The climatic and meteorological conditions will govern the diffusion, dispersion and radiation activity of the cloud. The fission and unfissioned material in an airburst will be distributed in the atmosphere, while in a subsurface waterburst, the adjacent water, ships and land facilities in

proximity to the detonation will be seriously contaminated. Fission products in the cloud may be dispersed as fine particles of varying size and depending upon many factors, fall-out of the radioactive material will occur on nearby areas. The fission products, therefore, present a continuing health hazard for a considerable time as an aftermath of the explosion. In general, irrespective of the technique of bomb detonation, radioactive materials emitting alpha and beta particles and gamma rays will be encountered. The half-life of these substances will range from a few seconds or minutes to days, months or even years. Violent changes in temperature, strong magnetic or electric fields, and drastic chemical interactions have no effect upon the rate of transformation or emission characteristics of the radioactive substance. If an element is radioactive, it will decay normally according to its inherent half-life.

In the underwater detonation of the bomb, thousands of tons of water rise in a column, a few thousand feet in the air, followed immediately by a rapidly moving mass of water, constituting the base surge. The turbulent waters contain a high percentage of the fission products and unfissioned residue. Immediately at detonation there is an enormous amount of radiation emitted. The falling column of water and mist, depending upon wind conditions and depth of detonation, contains a high percentage of the fission products and unfissioned residue which can seriously contaminate an area of several square miles for a considerable period.

The emission of infrared, visible, and ultraviolet light occurs a few milliseconds after the explosion. The ball of fire, in the airburst, grows rapidly in size. As it grows, its temperature and brightness decrease. Several milliseconds after the initiation of the explosion, the brightness of the ball of fire is several times the brightness of the sun. Most of the infrared and ultraviolet radiation is given off after the point of maximum intensity. The ball of fire rapidly expands from the size of the bomb to a radius of several hundred feet at one second after the explosion. Thus, the infrared and ultraviolet radiation comes in two bursts -- an extremely intense one lasting a fraction of a millisecond and a less intense one of much longer duration lasting several seconds.

The heat from the flash in an airburst occurs in a short time, and since there is no time for any cooling to take place, the temperature of a person's skin can be raised 50 degrees centigrade by the flash of infrared and ultraviolet rays in the first millisecond at a distance of over 4000 yards. People may be injured by flash burns at even greater distances. Gamma radiation danger does not extend nearly so far and the neutron danger zone is still more limited. High skin temperatures result from the first flash of high intensity infrared and ultraviolet and are probably as significant for injuries as the total dosages which come mainly from the second, more sustained ball of fire.

4. MAGNITUDE OF EFFECTIVENESS UPON PERSONNEL:

For personnel out in the open, within a half-mile of zeropoint of the airburst detonation, death would occur almost instantaneously or within a few hours due to blast, heat, and radiation effects. Within a radius of one-half mile and one mile from zeropoint, some individuals would die instantly, while a great majority would be seriously or superficially injured. Ordinary houses and structures would suffer complete destruction or extensive damage and fires would break out everywhere. Outside of a radius of one mile and within a radius of two miles from zeropoint, personnel would suffer various degrees of injury due to flash burns and indirect blast effects. Outside a radius of two miles and within a radius of four miles, personnel would be injured by flying fragments and suffer superficial wounds. Structures would be half or partially destroyed within this radius.

Assuming a city, similar to Washington, D. C., was attacked by an atomic bomb detonated in the air, it is estimated that 57,200 people would be killed or missing and 59,400 injured. The proportion of types of casualties would be as follows:

Wounds	-	70%
Burns	-	65%
Radiation	-	35% plus

These percentages, of course, would not add up to 100% because many of the patients will have multiple injuries.

In the main, death and injury to personnel resulting from the explosion would be as follows:

a. Flash burns from the instantaneous infrared and ultraviolet radiation from the explosion and secondary fires started by the burst.

b. Blast and Mechanical injuries caused by collapse of buildings, falling roofs, crumbling walls, flying debris, glass, direct, and indirect blast effects resulting in fractures, lacerations, contusions, abrasions, and other effects.

c. Radiation injuries due to nuclear radiations from the detonation, prolonged radiation from the resultant fission products, and radiation neutron induced radioisotopes.

5. EFFECTIVENESS UPON BUILDINGS:

Applying the results of studies of physical damage to the cities of Hiroshima and Nagasaki to American cities, some interesting comparisons can be made. Of course, no two cities, whether in Japan or in the United States, are exactly alike. However, worthwhile comparisons can be made. The differences in terrain, layout, zoning, density, and type of construction can be adjusted to arrive at comparable damage statistics. In general, the most striking difference between American and Japanese cities is in residential districts. Much of the damage can be applied to American cities and these figures would indicate what would happen to typical wood, brick, and stucco structures. Modern reinforced concrete and steel frames would fare bettere here - as they did in Japan. The following table focuses attention on how American cities are built and how few buildings are of blast-resistant construction. Population densities are also included.

TABLE I

Types of structures by exterior materials	NEW YORK	WASHINGTON	CHICAGO	DETROIT	SAN FRANCISCO
Structures Reported	591,319	156,359	382,628	267,677	105,180
Wood	236,879	48,971	131,148	165,488	61,172
Brick	299,482	95,939	238,959	94,333	2,384
Stucco	41,661	5,764	5,797	1,923	40,902
Other materials	13,297	5,685	6,724	5,933	722
Population Density					
Population	7,492,000	663,091	3,396,808	1623,452	634,536
Area Sq. Mile	322.8	61.4	206.7	137.9	44.6
Population Density per Sq. Mile	23,200	11,000	16,500	11,750	14,250

6. THE RADIOLOGICAL HAZARD:

In general, any radioactivity which remains in the area as fission products or induced radioisotopes may be included in this class. Fission products from the airburst bomb may be dispersed in the ground, or spread out over wide and diffuse areas depending upon the technique employed in the detonation. Consequently, the degree and extent of residual radioactivity would depend upon the height of detonation, climatic and meteorological conditions conducive to fall-out of the products in specific area, and the nature, and composition of the terrain. For example, due

to the height of the detonation, certain prescribed areas of the bomb crater might remain hazardous. Also, due to the composition of ground, dust particles intermixed with fission products might rise in the cloud. Many of these "dust particles" might also become radioactive as a result of neutron bombardment released at detonation and thus contribute to the hazard.

When the bomb is detonated over a modern city which contains countless thousands of items composed of iron, zinc, copper and other "neutron capture materials," it is possible that many of the elements within the effective neutron range may become radioactive for a considerable period. The half-lives of some of these common elements and the radiations emitted are listed:

TABLE II

PARTIAL LIST OF SOME COMMON RADIOISOTOPES WHICH MAY BE PRODUCED BY NEUTRONS RELEASED AT DETONATION

Radioisotope	Half-Life	Radiation
Sodium - 24	14.8 hrs.	Beta, Gamma
Sulphur - 35	87.1 days	Beta
Calcium - 45	180 days	Beta, Gamma
Iron - 59	47 days	Beta, Gamma
Cobalt - 60	5.3 years	Beta, Gamma
Copper - 64	12.8 hours	Beta
Arsenic - 74	16 days	Beta, Gamma
Gold - 199	3.3 days	Beta, Gamma

Therefore, objects or material, which might survive the detonation should be handled with precaution (medical supplies containing sulphur, arsenic, etc.) until the degree and extent of the induced radioactivity is determined. In some cases, it is possible that fission products are also present and are adhering to the material.

In an underwater burst, the main hazard, following detonation will be due to the deposition of a large percentage of fission products in the water and on nearby objects. In addition radioactive sodium is formed by the action of neutrons on the sea water. Some of the more persistent and hazardous fission products of U-235 are listed in Table III.

TABLE III

PARTIAL LIST OF FISSION PRODUCTS OF U-235
(Jour. Amer. Chem. Soc., Vol. 68, No. 11, pp 2411-2441)

Fission Product	Half-Life	Radiation
Strontium - 89	53 days	Beta
Strontium - 90	25 years	Beta
Yttrium - 91	57 days	Beta
Zirconium - 95	65 days	Beta, Gamma
Columbium - 95	35 days	Beta, Gamma
Ruthenium - 103	42 days	Beta, Gamma
Ruthenium - 106	1 year	Beta
Cadmium - 115	44 days	Beta, Gamma
Cesium - 137	33 years	Beta, Gamma
Barium - 140	12.8 days	Beta, Gamma
Cerium - 141	28 days	Beta, Gamma
Cerium - 144	275 days	Beta
Neodymium - 147	11 days	Beta, Gamma
Europium - 155	2 years	Beta, Gamma

From the foregoing, the radiological hazard can be divided into two phases. The first phase includes the immediate or prompt release of any ionizing particles or radiations due to the explosion during the period of visible flash of the bomb. These prompt ionizing radiations include beta particles, neutrons, X-rays, gamma (to a slight extent - ultraviolet), alpha particles (from unfissioned bomb residue) and the ionizing radiations from fission products. After the flash of the bomb has subsided (a few seconds), then the delayed phase of the radiological hazard is of importance. The hazard here is from fission and unfissioned material and from radioelements induced by neutrons from the explosion. The nature and persistency of the second phase depends on the many factors already discussed as to mode and technique of detonation. In addition to the phase of the radiological hazard, the protection problem is dependent upon whether the radiation concerned is external or internal to the body. Alpha particles for example, present no external hazard. However, if alpha particles are inhaled and finally become fixed in the bone, depending upon the amount, the results may be lethal.

It is obvious that very little can be done from the standpoint of protection for personnel in the open within the lethal range at the instant of detonation. However, in the second phase, when fission products and induced radioactivity might be encountered, a few facts concerning the ionizing particles are of interest.

TABLE IV

RELATIVE COMPARISON OF RADIATIONS.

Nature	Description	Range Air	Range Tissue	Ionizing Power*
Alpha	Helium nucleus 2 protons & 2 neutrons	0.1 ft	0.01 cm	10,000
Beta	Electron emitted from nucleus	10 ft	1 cm	100
Gamma	Electromagnetic radiation from nucleus	1000 ft	10 cm	1

*Note: For each ion pair formed by a gamma ray, 10,000 ion pairs are formed by an alpha particle.

The relative protection against gamma radiation by shielding is given by lead, iron, concrete, earth, water and air, in order of effectiveness. Using the gamma radiation from radium as an illustration, approximately five times the thickness of concrete is required to equal the protection afforded by a layer of lead. Where no shielding is available, "distance" is the best means of protection. It should be noted that neutrons pass through lead with extreme ease. However, neutrons are readily absorbed by hydrogenous materials, water, boron, or cadmium.

7. THE FLASH BURN EFFECT:

At detonation, the injuries due to flash burns from the infrared and ultraviolet causes a higher percentage of casualties than the radiological effect due to the greater range of the flash burn types of radiation. Light shades of loosely-fitted clothing, antiflash cream and protection of entire surface of body will reduce percentage of casualties. Protection by these means of course will not reduce effects of burns produced by secondary fires in buildings or facilities. Problem here is to minimize the amount of material of inflammable character to a minimum practical to the situation. In this connection, materials which ignite easily should be avoided in the design of equipment intended for military operations. Flash burn is not a factor in an underwater detonation.

8. DECONTAMINATION PROBLEM:

As mentioned previously, it is impossible to alter, speed up or change the rate of decay of a radioelement (fission product or induced radioisotope). Fission products tenaciously cling to porous materials, such as concrete, wood, fabrics, rope, painted and rusted areas, while hard surface materials, such as stainless steel fare better. Decontamination is a tedious and difficult problem.

A.F.S.W.P.
INDOCTRINATION COURSE FOR MEDICAL OFFICERS

Essentials of Instrumentation

Dr. Howard Andrews

The detection and measurement of high energy radiation depends entirely upon the proper use of suitably constructed instruments since nature has not seen fit to provide man with senses capable of responding to it. Without instruments even intense radiation fields will not be recognized until irreparable damage has been done. If photographic film and a few special methods are excepted, all detecting devices are based upon the ionization produced in gases by the incident radiation. When an ionizing agent enters a gas, it may act on a neutral atom or molecule with a force large enough to remove one or more electrons from the atom. It is most probable that two ions will be formed, and so it is customary to speak of the formation of <u>ion pairs</u>. The average energy loss per ion pair in air is about 33 electron volts.

If ions are formed in a gas subject to an electric field, they will move in opposite directions, the negative ions toward the positively charged anode and the positives toward the negatively charged cathode. The current flow will be extremely small, and special measuring devices are required to detect it. Because of the mutual attraction of oppositely charged particles there is always a tendency for ions to recombine and form neutral atoms. The chance of recombination is greater the longer the time before the ions reach the electrodes. The fraction lost decreases with increasing voltage, and eventually all of the ions are collected so there is no further increase in current. This condition is known as saturation, and the maximum current is called the <u>saturation current</u>.

Instruments for measuring the amount of electric charge collected in an ionization chamber are known as electroscopes and electrometers. The Lauritsen electroscope is one of the most generally useful instruments for radiation measurements. The moving system is a quartz fiber about 5 microns in diameter, made conducting with a thin metal coating and cemented to one arm of an L. Mutual repulsion causes the quartz fiber to deflect. Ions formed inside the case will neutralize the charge and the fiber will return toward its uncharged position.

Another useful quartz fiber instrument is the pencil type electroscope, or dosimeter. This is essentially a Lauritsen electroscope modified so that the entire instrument is about the size of a large fountain pen. Instruments of this type are very useful for measuring integrated exposures. They can be made with a sensitivity such that 0.1 roentgen will produce about one half of full scale deflection.

Ionization chamber instruments vary widely depending on the particluar type of radiation to be detected. Short range radiation is admitted to the chamber through a suitable window. Thin mica or stretched nylon film about 0.0001 inch thick is satisfactory for alpha particles. If beta particles are to be measured, the windows need not be so thin. When a photon enters the ion chamber and is absorbed; high speed electrons are produced which travel through the gas in the chamber producing ions until their kinetic energy is spent. For 0.2 Mev X-rays this requires a chamber about 20 centimeters in diameter.

A small portable chamber should have the same absorption for X- and gamma rays as the air in the standard chamber and should also have the equivalent of the long air paths for the absorption of the high energy electrons. Chamber walls are regularly made of bakelite or plastics which contain a high percentage

of carbon atoms. Since human tissue is composed chiefly of carbon, oxygen, nitrogen, and hydrogen, such an instrument will simulate absorption by the body. Ionization chambers designed on these considerations are known as thimble chambers. One successful thimble chamber instrument is the condenser gamma meter.

The condenser gamma meter is not entirely satisfactory for survey purposes. The chambers must be charged, left in the radiation field for an appropriate time, and then read with the meter. If a large contaminated area is to be surveyed, the number of chambers required becomes exorbitant. This requires an instrument which will give a steady deflection that is proportional to the amount of radiation striking the chamber. Unfortunately ionization currents are too small to be measured with portable meters, and it is necessary to use other means. It is perfectly feasible to measure currents of this order with suitable vacuum tube circuits.

Geiger-Mueller (G-M) counters take advantage of the gas amplification that can be obtained when high accelerating voltages are applied to an ionization chamber. When an ion has an energy greater than the ionization energy of the gas molecule, it may produce secondary ions upon collision. The secondary ions formed will in turn be accelerated by the electric field and may produce further ionization. This cumulative effect is known as Townsend or avalanche ionization. If a total of A ion pairs results from one original pair, the process is said to have a gas amplification factor of A. In practice A varies from about 10 in gas-filled photoelectric cells to 10^8 in some Geiger-Mueller counter tubes. At a pressure of 10 centimeters of mercury, gas amplification can be obtained at voltages of 250-1, 500 volts depending on the gas and the

tube dimensions. G-M counters usually have a cylindrical cathode from 1 to 10 centimeters in diameter with a length from 2 to 10 times the diameter. The anode consists typically of an insulated axial wire 0.001-inch to 0.005-inch in diameter.

Assume such a counter exposed to a constant amount of radiation, each ionizing particle or photon having the same energy. Each ionizing particle entering the chamber will produce a definite number of ion pairs in the gas, and these ions will proceed to the collecting electrodes where they will be neutralized and will produce a pulse of current in the external circuit. If now the size of the pulse is plotted against the voltage applied to the electrodes, a curve similar to that of figure 1 will be obtained. Regions A and B represent the normal ionization chamber working conditions where the only ions contributing to the pulse are those produced by the original radiation. Over region C there is some gas amplification occurring very close to the central wire. In this region the gaseous amplification is quite stable for any given voltage and does not depend on the number of initial ions present. Thus if the voltage is adjusted to a value such that the gas amplification factor is 10^3 and an incident beta particle produces 100 ion pairs, the pulse received at the electrode will be $100 \times 10^3 = 10^5$ ions. Under the same voltage conditions an alpha particle producing 10^5 primary ion pairs will yield a pulse of $10^5 \times 10^3 = 10^8$ ions. Because of the rather strict proportionality between the amounts of initial and total ionization this portion of the curve is known as the <u>region of proportionality</u>, and a counting tube operating in this region is called a <u>proportional counter</u>. A proportional counter can be used to measure alpha particles or neutrons in the presence of strong beta and gamma radiation.

If the voltage is raised still further, the gas amplification factor will continue to increase, but in region D the amplified pulses are no longer proportional to the number of primary ions. A sort of saturation effect begins to enter at this point and consequently a few primary ions will produce nearly as many total ions as are obtained from a large number of primaries. There is still some difference in final pulse sizes however, so this region is known as the region of limited proportionality.

The gas amplification continues to increase with further increases in voltage, and region D gradually changes to region E where all proportionality ceases. Here a single ion pair is sufficient to produce an amplified pulse of the same size as that obtained from a large number of primary ions. This is known as the Geiger region and is characterized by gas amplification factors of the order of 10^8. This is the portion of the tube characteristic commonly used for counting beta and gamma radiation. The Geiger region usually extends over a range of about 200 volts. When still higher voltages are used, the region of continuous discharge, F, is reached. In this region the tube is too unstable for useful operation, and care must always be taken to keep the tube voltages below the continuous discharge value. Actually the tube does not go into continuous discharge but rather produces a series of closely spaced pulses from one initial ionizing event.

A second type of characteristic curve is helpful in understanding the operation in the Geiger region. Assume the tube to be exposed to a constant radiation intensity but with the incident particles or photons having unequal energies. Pulses per second when plotted against the applied voltage yield a curve similar to figure 2.

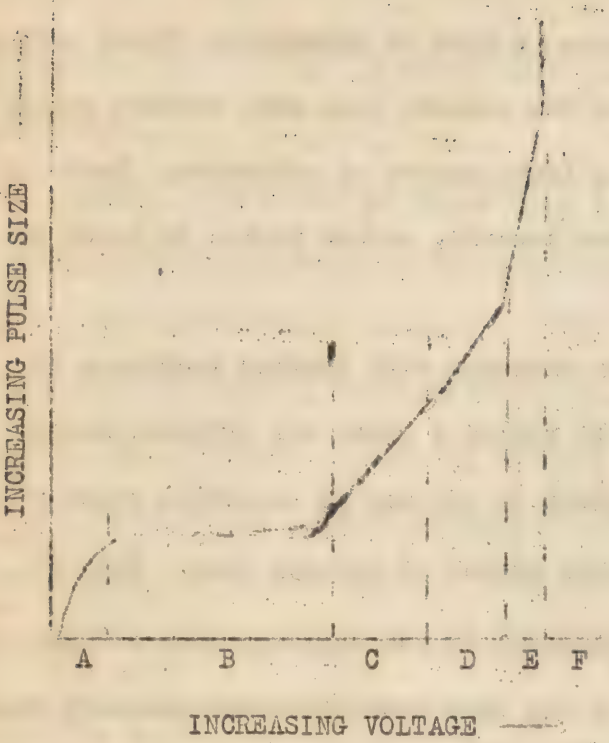

Figure 1 - Ion chamger pulse size versus voltage.

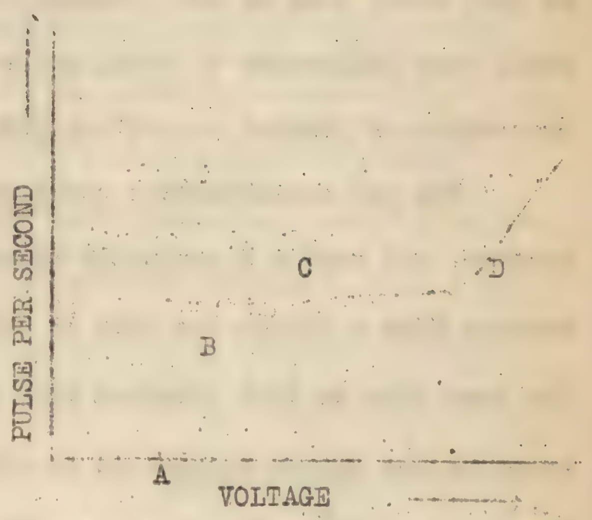

Figure 2 - G-M tube characteristic

The associated electronic equipment for recording the number of pulses will not respond to the small pulses produced in the ionization chamber region where there is no gas amplification. Consequently the curve will have a threshold, A, below which no pulses will be recorded. As the voltage is raised and the gas amplification becomes appreciable, the most energetic particles will be counted, but the weak ones will be lost. This is the region of proportional counting AB. As the gas amplification continues to increase with voltage, more of the less energetic particles will be counted until point C is reached. C is the threshold of the Geiger region CD, and here practically every particle entering the tube is counted. D is the threshold of the continuous discharge region.

The Geiger region CD is known as the plateau, and it is obviously desirable for a tube to have a long, flat plateau since here the counting rate does not depend strongly on the applied voltage. To obtain desirable plateau characteristics the filling gas and pressure must be carefully chosen, and the central wire must be free from dust, sharp points or diemarks. Oxygen and water vapor are particularly undesirable and must be completely removed before filling. Argon is a very satisfactory gas and is used in practically all counters.

Near the central wire a large number of electrons and positive ions will be formed in the avalanche. The electrons have a small mass and are already close to the central wire so they will move toward it with high velocities and will be completely collected by the wire in 10^{-6} seconds or less. The positive ions, on the other hand, have to travel out to the negatively charged cylinder. Since they have comparatively large masses, they move much slower than the electrons. The positive ion cloud will reach the cylinder in perhaps 10^{-3} seconds, long after the electrons have been collected at the wire.

As a positive ion approaches very close to the cylinder, it will pull an electron from the cylinder and become a neutral molecule. In general the electron will go into one of the upper energy levels so the molecule, although neutral, will be in an excited state. The molecule will, however, promptly return to the ground state and in so doing will radiate a characteristic series of spectral lines. Some of these lines will be in the ultra-violet region of the spectrum and consequently will have sufficient energy to liberate photoelectrons from the metal cylinder. With high tube voltages a single photoelectron will be sufficient to start a second avalanche and thus the entire process will be repeated over and over again.

It is possible, however, to construct counters in which the discharge can be stopped. These are known as <u>self-quenching</u> or fast counters. A self-quenching counter can be produced by adding to the usual filling gas a small amount of a polyatomic vapor, such as alcohol or xylene. These complex molecules strongly absorb ultra-violet light, and by this mechanism the photoelectric emission at the cathode is prevented. Most of the polyatomic molecules introduced to make self-quenching counters are vapors at room temperature, and these counters are apt to show a sensitivity which changes with temperature. A further disadvantage lies in the fact that some of the quenching gas is broken down (dissociated) at each discharge, and so these counters have a limited life. A very satisfactory self-quenching counter can be made by filling the tube with 10 percent alcohol and 90 percent argon to a total pressure of 10 centimeters of mercury. With a non-self-quenching tube an auxiliary circuit must be used to stop the discharge.

Any counter will give counts when placed in a neutron field, but better results can be obtained with specially designed tubes. To detect slow neutrons the counter is filled with boron trifluoride, BF_3, which is a gas at room temperature. A slow neutron may produce a nuclear reaction with the boron. This reaction liberates a considerable amount of energy, and the alpha particle and the recoiling lithium will have sufficient kinetic energy to produce heavy ionization which will trip the counter. By using the counter in the proportional range it is possible to obtain a count for each disintegration even in the presence of large beta and gamma intensities. The capture probability decreases with the neutron velocity so the reaction is not efficient for fast neutrons.

Fast neutrons may be detected through the recoil atoms which they produce when they collide with the gas atoms in the counter. The recoil atoms produce intense ionization, and hence if the counter is adjusted to the proportional range, the counter will discriminate against beta and gamma radiation. Fast neutron counters have a rather low efficiency because of the low cross section for the collision process. Neutron counting is complicated by the change in behavior with velocity, and the present neutron counters are far from satisfactory.

None of these devices gives an absolute measure of radiation intensities. It is therefore necessary to calibrate them in terms of known standards. This is not difficult if a gamma ray calibration is required in terms of roentgens. It has been established by careful measurements that 1 milligram of radium, in equilibrium with its products and enclosed in 0.5 millimeters of platinum or its equivalent, will produce an intensity of 8.4 roentgens per hour at a distance of 1 centimeter. The inverse square law can be used to calculate the intensities at other distances. Standard γ-ray sources, properly aged and carefully calibrated, are available from the National Bureau of Standards. Calibration of X-ray measuring instruments should be carried out against primary standard ionization chambers or carefully calibrated secondary standards by a well-equipped laboratory such as National Bureau of Standards or by a reliable instrument manufacturer.

In making alpha and beta particle measurements quite different considerations enter. Radioactive materials emit particles in all directions with equal probability and in general a chamber or G-M tube will intercept only a fraction

of the total emission. For example, if the active material is spread in a thin layer on the bottom of the chamber, only one-half of the ejected particles will reach the gas and produce ionization. It is then necessary to calibrate the chamber in terms of a known radioactive material. Various members of the naturally radioactive series are useful for this purpose.

Photographic materials are also important tools for the measurement of radiation since high speed particles and high energy photons produce developable images. Although photographic films and papers lack the accuracy attainable in the laboratory by electrical methods, they still play an important role in radiation measurements. A film is one of the simplest detectors of radiation, is small and light, can be obtained with a wide range of sensitivity, provides a permanent record of exposure, andhas no complicated electronic circuits to get out of adjustment. For many applications these facts more than outweigh the disadvantages of film processing, the time required to obtain a measurement, and the variations inherent in photographic materials.

TABLE I

Emulsion:	Useful sensitivity range (roentgens)
Type K	0.05-2.0
Type A	1.0-10
Cine positive 5301	5-80
Cine positive fine grain 5302	40-400
Kodalith 6567	70-700
Kodabromide G-3	400-8,000
548-0, double coat	2,000-10,000
548-0, single coat	5,000-20,000

Table I lists a series of emulsions that have proved useful for measuring beta and gamma radiation. It can be seen that a single emulsion will cover an exposure range of about 1-10.

Photographic film meters are usually made into packets of dental film size (1 1/4 x 1 3/4 inches) and covered with an opaque wrapping to protect the film from visible light. Any combination of suitable emulsions can be put into a single packet. A cross of thin sheet lead about 1 mm thick is customarily attached to the packet. This absorber is sufficient to stop all beta particles so any darkening under the cross will be due to gamma rays. The cross also serves to enhance the darkening due to gamma rays because of the larger number of electrons ejected from the lead. The regular wrapping is sufficiently thin to permit the penetration of all but low energy beta particles. Thus the film can be used to measure both beta and gamma exposures.

In general, film processing is carried out in accordance with the manufacturers' recommendations, but variations may be used satisfactorily. Whatever procedure is used, it is most important to control time and temperature as accurately as possible. The developer should be in a tank surrounded by a constant temperature bath, and the films agitated throughout development. The importance of time and temperature control, scrupulous darkroom technique, and the use of fresh chemicals cannot be overemphasized.

Special emulsions are now commercially available which are almost insensitive to visible light, beta and gamma radiations, but which will respond to heavy particles such as protons, deuterons, or alpha particles. These particles have such a low penetrating power that the emitting substance must be placed in direct contact with the emulsion. These emulsions are not used for personnel monitoring but rather to detect alpha particle contamination. These emulsions will detect alpha particles in the presence of strong beta and gamma radiation,

and under conditions that make the operation of electrical alpha particle detectors uncertain if not impossible.

With weak exposures the plate will not be uniformly darkened and individual alpha particle tracks can be seen in a microscope. Since alpha particles are emitted with an energy characteristic of the emitting nucleus, the track lengths may frequently be used to identify the alpha emitter.

The various film emulsions can be used to make radio-autographs of specimens containing radioactive materials. By exposing sections of the specimen it is possible to determine the cross-sectional distribution as well. However, it must be emphasized that the resolving power of photographic emulsions for determining the precise position is limited, and it is scarcely possible to determine the location of radioactivity to less than 1/100 mm.

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Talk Before Medical Conference on Atomic Energy
at
Army Medical Center

PROTECTION AGAINST ATOMIC BOMBS
by
William W. Stone
Major, Cml C

In considering protection against atomic bombs the words protection and defense are almost synonymous. We will treat this subject by dividing it into two (2) broad categories: passive defense and active defense. Because of the nature of this conference emphasis will be placed upon those factors bearing a relatively close relationship to medicine. For completeness, however, other aspects will be mentioned.

It is important to realize from the very beginning that the important effects of the atomic bomb against which protection must be developed are:

1. Blast or Shock Wave
2. Visible and Near-visible Radiation
3. Nuclear Radiation
4. Psychological Effects

I. PASSIVE DEFENSE AND PROTECTION:

1. In considering all of the effects of the atomic bomb it should be noted that these influences all decrease in intensity extremely rapdily as one moves away from the point of detonation, thus it is apparent that distance is always the best protection. In devising methods of protection one always has the very difficult job of fighting against this extremely rapid fall-off with distance of the factors capable of creating damage.

a. Primary shock, or blast damage, is defined as the compressive and tearing action of the shock wave on the human body. When one interposes between the blast and the body an object of strength similar to that of an ordinary wall, this form of damage is effectively reduced. Primary shock is thus of importance only when a person is in the open and exposed simultaneously to lethal amounts of other effects of the atomic bomb. Living things are remarkably resistant to this form of damage and are much stronger in this respect than normal buildings. Underground shelters and normal reinforced concrete buildings protect against this effect up to very close to the point of detonation. This damage in its mildest forms is seen as petechial hemorrhages of the lung. In its severest forms major abdominal hemorrhages appear.

b. Secondary shock or blast damage is extremely important and is defined as being due to flying objects hitting and lacerating the body. A shock wave is very much like an extremely strong wind which lasts for about a second. This wind is strong enough to throw the body many feet. It also breaks windows, knocks down plaster, and throws other objects around with great violence. When these objects strike a human or the human strikes an object, secondary shock damage, or trauma, results. There are many things that the individual can do for himself to reduce his chances of this type of injury if he has some advance warning of the detonation. It is obvious that he should keep away from the windows and that he should get flat on the floor or ground. One should avoid standing under overhanging cornices, beneath chimneys and other heavy objects which are easily knocked down. Underground installations or shelters greatly reduce this effect because very little of the air shock is transmitted through the ground and thence into shelters or basements. In Japan, this form of injury combined with burns accounted for most of the casualties. The rapid follow-up of the fire on the blast damage caused many fatalities among the injured. Injuries of this type require evacuation, treatment and hospitalization. In the case of primary shock damage there is an amazingly small boundary zone. One is either dead immediately or all right as far as this effect is concerned after a few minutes. There is much that can be done in the design of vital installations to reduce damage from these secondary shock effects.

c. Flash burns are those injuries which are created by direct exposure to the visible and near-visible radiation emanating from the point of detonation. The thinest type of non-transparent material will shield effectively from this effect. Light colored clothing is particularly good as it reflects almost all this radiation. Dark colored clothing will not transmit this radiation but will catch fire and produce flame burns on the skin beneath the clothing. This form of damage is important only when the person is in the open and in direct line of sight from the point of detonation. Because of the nature of the atomic bomb this form of damage occurs at greater distances than those caused by any other effect.

d. Flame burns are those injuries which are produced by fires started in inflammable material or buildings. These effects were very prevalent in Japan but would be expected to occur to a lesser degree in an American city. The possibility of fire and subsequent injury can be greatly reduced by making structures less inflammable. Also, the development of adequate and large amounts of fire fighting equipment and trained personnel can furnish great protection. To reduce this form of damage it will be necessary to have fire fighting equipment and personnel so located that a major proportion will not be wiped out by the detonation. Reading of the

accounts of Hiroshima and Nagasaki points out the complete inadequacy of Japanese fire fighting equipment and procedures. In both cities, about 90% of the equipment and personnel for these duties were wiped out immediately. Major efforts should be placed on reducing the possibility of this type of personnel damage, not only because of its capabilities of producing a very large number of casualties, but also because these casualties subsequently need even larger amounts of personnel and equipment for treatment and hospitalization.

e. Nuclear Radiation. The utilization of nuclear radiation in warfare presents completely new problems for both the military and the civilian. These effects are not only important but complex. They constitute the primary reason for this conference. In considering this subject we will break it down into several categories. The most important division is into external and internal hazards. Another division which is of importance and helps to clarify the situation is to divide these effects into immediate and delayed hazards. For all nuclear radiation effects the general statement is again pertinent - that distance is by far the best protection.

(1) Prompt or immediate radiation: By prompt radiation we mean those forms of damage which are produced in a matter of a few thousandths of a second after detonation. With the atomic bomb roughly 99% of the nuclear radiation produced comes out in the first small fraction of a second after the detonation. These radiations emanate from the detonating bomb and the ball of fire is formed immediately afterwards. They consist of penetrating radiations which come from outside the body. Hence, all prompt nuclear radiation is described as an external hazard.

Large amounts of gamma rays come out almost immediately from the detonation, radiating in all directions. These rays travel in a straight line as does light. They are highly penetrating and it takes a large amount of material to absorb and stop them. It is of importance to realize the directional and shadow producing characteristics of this radiation. One does not need shielding on all sides but merely between one and the point of detonation. In shielding against gamma radiation the important thing is the weight of the material which is between you and the source. The chemical characteristics of the constituents are of no importance. Lead is often used in laboratories where gamma radiation or X-radiation occurs. This is a suitable substance because it occupies a very small volume in comparison to its weight. Equal weights of water, steel, concrete or wood are just as effective except for their space con-

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suming characteristics. The effectiveness of a shield is most often described by means of thickness of the material which is necessary to reduce the intensity to one-half (1/2) the initial amount. This is called the half-thickness of that material. It is useful to know very rough half-thicknesses for common construction material. They are:

3" for concrete
4" for wood or earth
1" for steel

Neutrons also constitute an external hazard at the time of the detonation. They are not as effective at great distances as the gamma rays but require consideration. Because neutrons are uncharged particles, they are difficult to stop and shield against. Shielding is not as simple as in the case of gamma radiation because weight of the shielding is not the important factor. Instead, the important characteristic is the ability of the particular chemical or element to slow down and then capture neutrons. The neutrons which occur in the detonation of an atomic bomb are essentially fast neutrons. Substances such as cadmium and boron capture slow neutrons to an amazing degree. Because these neutrons are not slow these substances are of no particular value in defense against the atomic bomb. The best substances are those with low atomic weights. Hydrogen, the lightest of all substances, is the best; hence, in shielding against neutrons the best substances for their weight are those containing large amounts of hydrogen. Such shields would be materials like water or paraffin. Very rough half-thicknesses can be given for common structural materials and are as follows:

Somewhere between 3" and 12" for steel
About 6" for concrete, earth or wood
About 6" for water.

Neutrons like gamma rays also travel in a straight line from the point of detonation, going in all directions. Hence the shielding need be only between the person and the source.

(2) Delayed radiation. We will consider here that one percent of the nuclear radiation which does not come off immediately but which comes from the decay of the fission products produced by the nuclear

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explosion. In an air burst, where the fire ball and mushroom cloud containing the fission products go up in the air to be dispersed by the wind, this delayed radiation is negligible. In an underwater burst, or possibly a surface land burst, a base surge like Test BAKER at Bikini will probably occur. This cloud moving along close to the ground contains a large proportion of the fission products. As this cloud sweeps out over ships or cities it surrounds buildings, people and equipment. The radiating material is then extremely close to a person. And the relatively small amount of radiation that is left after the detonation is greatly enhanced because of its proximity. This base surge, in comparison to the mushroom cloud after the air burst, produces radiation intensities on the ground which are higher by a factor of thousands, perhaps millions. This is due solely to the fact that the base surge can surround individuals on the ground. When it is realized that at Test BAKER this base surge moved over an area of roughly 5 square miles, this is seen to be a very real hazard. It, of course, takes time for this cloud to move, and, as the radiation from it is only of importance when it surrounds the point in consideration, there is available a varying amount of time in which to get out of the way or to dodge the cloud. This base surge moves with varying speeds. Initially it spreads out at about 50 mph. Its speed constantly decreases until it reaches zero at its outer limits. For this cloud to spread over its maximum area requires several minutes. If one is in a city, great protection will be afforded if one gets down into a basement or subbasement, or into an air-raid shelter. It is of importance also to note that this radiation from the base surge is non-directional as it comes from all points in the cloud. Hence, any shield which is devised must be on all sides, including on top of, the location considered.

Delayed gamma radiation from the base surge is similar to prompt gamma radiation except in its non-directional characteristics. The shielding requirements are similar to the previous situation in that the same half-thicknesses are applicable.

There are no delayed neutrons of significance; hence, special shielding is of no importance for this problem.

In the delayed situation we also have important beta radiation. Prompt beta radiation does occur but does not travel a very great distance from the source because of the efficient shielding furnished by air. Where the base surge is surrounding the location in question, beta radiation is important because the half-thickness of air is roughly 3 or 4 yards. Normal clothing furnishes sufficient shielding to beta radiation. Similarly thin walls and the glass in windows are adequate. It is of course non-directional and comes from all sides. The extent of the external hazard furnished by beta radiation is not well understood. It is believed comparable to that of gamma radiation when a base surge has been created.

Alpha radiation, of course, occurs from the non-fissioned material; in other words, plutonium or uranium is its source. This radiation constitutes no external hazard as the skin furnishes adequate shielding. All the alpha rays are absorbed in the epidermis with no resulting damage to living tissues.

(3) Nuclear radiation (internal). With an internal hazard we have the situation where radioactive materials, either fission products or non-fissioned material, gets into the body through inhalation, ingestion or injection. This is, of course, a delayed hazard and is possible only where one is in the base surge, in the mushroom cloud, or working in an area over which the base surge has previously passed. The internal hazard occurs generally only where there is also an external hazard. If one is exposed to the base surge or is in the mushroom cloud the external hazard is often lethal in its own right without any consideration of an internal hazard. Particularly if one is working in a highly contaminated area after the detonation, there is a significant but not necessarily lethal amount of external hazard but there is also a very great internal hazard. This is created by disturbing the deposited material by kicking up dust and is usually gotten into the body through inhalation. An additional hazard exists from eating with contaminated hands and thus getting the active material into the body through the mouth.

It is important to realize that in the case of an atomic explosion on a small amount of this

active material it is in the form of a true gas or vapor. Almost all of it exists on particles of dust or droplets of water. Protection against these particulates is probably achieved with the use of ordinary gas masks containing modern filters. These contaminated particles have a size range of from 0.1 microns to 10 microns. The filters on modern gas masks such as the assault mask are believed to be quite adequate. These filters are extremely efficient. It is quite possible that new masks will be coming out which have adequate protection for atomic warfare, biological warfare and chemical warfare. Such a development of course is highly desirable.

It is probable that protective clothing will be required for workers entering contaminated areas. It would probably be permeable clothing. Its main requirement is that it should be disposable. Its functions would be to keep contaminated material from the skin and possible later entry into the body. Disposability is desirable as these materials cannot be rendered harmless by any physical or chemical means.

Collective protectors with filters or inclosed air conditioning systems are probably indicated for vital installations and underground shelters in anticipation of atomic warfare. Such items would prevent the entry of the highly contaminated air of the base surge into installations which otherwise would furnish adequate protection against the effects of the atomic bomb.

The development of decontamination techniques and facilities is indicated to reduce the very long term possibility of personnel becoming contaminated and later having active material enter the body through the oral and digestive tracts. Such techniques will probably consist of washing away, carrying away, or burying the active material.

f. Education. In an attack on a modern city it is believed that approximately 50,000 mortalities would be created by a single bomb. It is felt that if the individual civilian and soldier in these cities or installations were adequately trained as to what he could do for himself after the detonation occurs, that perhaps 10,000 lives could be saved. Exactly how much and what kind of education this requires is not yet known. It is believed to be relatively simple and is obviously important. The development of atomic defense for the individual will be the subject of much work in the future. Also

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of importance is the education of large numbers of personnel, both civilian and military, for special jobs in atomic warfare. This requires a much greater degree of education and will probably be given to such people as radiological safety personnel, medical officers and civilian doctors, civil defense technicians, etc. The method by which the individual indoctrination and the specialized training is given will determine to a large extent the psychological preparation which will be attained in a population. It is highly desirable that the proper amount of knowledge be given to all so that there is created a proper respect for the special hazards of atomic warfare and that we avoid the undesirable extremes of excessive fear or ignorance. This will be a difficult job and the nation is far from attaining this ideal situation at the present time.

g. A large amount of detailed defense planning will be required for protection of the nation. It will include large scale training of such specialists as fire fighters, evacuation control personnel, first aid personnel, and decontamination groups. Large stock piles of food supplies, medical supplies and disaster equipment will be required in relatively invulnerable locations. Preparations will be required for mutual aid between cities and major installations.

h. All groups, civilian and military, will need to be equipped and trained in the detection and isolation of contaminated areas. This new hazard created by nuclear radiation is the one hazard which may not be detected by any of the physical senses. It requires special instruments and special consideration.

i. With sufficient indoctrination and a few minutes advance warning that an attack will occur, it is quite possible that a 50% saving in mortalities and casualties can be effected. This establishes the fact that development of advance detection techniques and warning signals is of the greatest importance to insure the continuation of our present existence.

II. <u>ACTIVE DEFENSE</u>:

1. Of less direct importance to the medical profession but of the utmost importance to the nation is active defense, which by its name means the actual prevention of an atomic attack. Regardless of our degree of preparation and protection, large numbers of casualties and a more important amount of disorganization and dislocation will occur.

a. United Nations Organization. The attempts of the UNO to set up machinery to insure peace in the future will be by far the greatest protection we can possibly have against the atomic bomb if it is successful. We realize, however, the difficulties of getting agreement among nations which is required.

b. Military preparedness. The basic responsibilities of military organizations require that they assume that war will occur. Otherwise they are negligent in their duties. Regardless of the political situation the military must constantly endeavor to have its preparedness kept at the highest level. In the case of atomic warfare this will consist of extensive stockpiling of all weapons, including atomic bombs. It will require readiness of retaliation forces. Because of the nature of the atomic bomb it will require extensive protection of our ability to retaliate and conduct an offensive war. As was seen above, advance warning is most important - thus an efficient foreign intelligence corps is vital. Some persons have raised the provoking thought that, because of the capabilities of the atomic bomb, we will lose an atomic war unless we attack first, assuming the enemy has atomic bombs.

c. A vital part of active defense which is, in my opinion, erroneously played down in articles in the press is the believed futility of interception of an atomic bomb carrier and thus preventing delivery of the bomb on the target. Within the last few weeks our authorities on guided missiles have stated openly that it is their belief that guided missiles cannot be used as a carrier for at least another 10 or 15 years. The military must consider the intervening years in which it is anticipated that manned aircraft are the most likely vehicle. We have had only a fair degree of success in the interception of aircraft on bombing missions. There is no scientific reason why our degree of interception can't be raised to nearly 100% if a tremendous amount of money, time and technical ability is put on the problem. Atomic warfare, as you have seen, presents a truly horrible outlook. It is our duty to push to the utmost any procedure which could possibly reduce its effectiveness against us.